MINERALOGY OF BEACH SANDS

BETWEEN HALFMOON AND MONTEREY BAYS, CALIFORNIA

By C. OSBORNE HUTTON

School of Mineral Sciences
Stanford University

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ABSTRACT

A study has been made of the nature of the heavy mineral assemblages in beach sands on a strip of the California coast from the north end of Halfmoon Bay to Pacific Grove, south end of Monterey Bay. Although samples were collected over a three-year period and at different seasons, specimens obtained from any specific locality at different times were not found to vary significantly, one from another.

The methods used in fractionation of heavy minerals from crude sands included elutriation, flotation in heavy liquids, electromagnetic and centrifuge separation and hand-picking. Electromagnetic work has provided a considerable amount of data on magnetic susceptibility of a range of minerals of known composition.

In all, 35 minerals or mineral groups have been recognized by determination of physical properties and/or chemical composition. Among these, perhaps, the most interesting from a purely mineralogical point of view are cassiterite, chrysoberyl, diamond, dufrenite, monazite, pyroxenes and amphiboles that display most remarkable etch features, euxenite, tantalite, and uranoan thorite. Complete chemical analyses of biotite, monazite, and thorite have been made and are discussed in relation to their structural formulae and physical properties; from the Pb/Th,U ratios in monazite and thorite, tentative ages have been calculated. An age of 106×10^6 years, approximately mid-Cretaceous, has been determined for the monazite that is clearly derived from the granitic rocks at Monterey.

The recognition of the nature of non-translucent mineral particles has proved difficult, but magnetic fractionation has been helpful, and inspection in oblique illumination with a wide field binocular microscope is absolutely necessary. Of considerable value were chromatographic techniques, use of alpha-ray track plates, and the NaF-Na_2CO_3 fusion mixture for detection of uranium-bearing minerals.

A complete study of the problems of provinance has not been attempted at this stage, but it is pertinent to say that, in most instances, the heavy minerals in the beach sands have been derived from plutonic intrusives, sediments, and associated submarine lavas and tuffs that make up the drainage area of streams that reach the Pacific Ocean in this locality. The source of thorite, chrysoberyl, euxenite, and tantalite, all minor or rare constituents, has not been determined.

MINERALOGY OF BEACH SANDS BETWEEN HALFMOON AND MONTEREY BAYS, CALIFORNIA

By C. Osborne Hutton

INTRODUCTION

This work was undertaken primarily to determine the nature of the minerals in blacksand paystreaks (concentrations of dark minerals in minor beds, lenses, or irregular layers), the composition of the heavy minerals in average beachsands, and subsequently to determine the distribution of such constituents along a section of the central California coastline.

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DISTRIBUTION AND NATURE OF SANDS

Sands were collected from many localities between the north end of Princeton Beach, San Mateo County, Santa Cruz, Santa Cruz County, and Pacific Grove, Monterey County, at the south end of Monterey Bay (see figure 1). Forty-nine samples of blacksand paystreaks from 17 localities, and 86 typical sands from these and other localities were collected along the coastline. Blacksands are relatively numerous, nowhere show great lateral extent or depth, and in many places are only transient. Storm conditions appear to favor active concentration of the heavier constituents in these sands. However, some blacksand concentrations appear to be relatively stable. They are particularly well developed in the following localities: Princeton Beach just south of the pier, south side of the mouths of Tunitas, San Gregorio, Año Nuevo Creeks, south of Pigeon Point Lighthouse (rocky shoreline with shallow depth of sand), several points east of Año Nuevo Point, and at many points between Pajaro River and Moss Landing in Monterey Bay. Paystreaks that occur between the mouth of Salinas River and Monterey appear to have a stability of an intermediate character. The presence of a headland or river effluence immediately to the north of blacksands is common and these obstructions, by altering the direction of southward-moving ocean currents, or by reducing velocity, have permitted deposition of the heavier part of the sedimentary load. In localities where blacksands are especially well developed, such as the mouth of Tunitas Creek, plentiful driftwood makes post-hole sampling difficult.

Although grains of specific minerals may exhibit a high degree of roundness and polish, the constituents of the sands generally are angular, with quartz and feldspars particularly so. The average grain size does not vary notably from place to place and most of the sands may be classified as medium-grained or fine-grained (Wentworth, 1922). Blacksands tend to be finer grained than sands showing little accessory mineral concentration, but the ratio of heavy minerals to light increases notably with decrease in grain diameter (figure 2). This is particularly evident in the very fine-grade and silt fractions, since they are made up almost entirely of heavy minerals, but such fractions rarely make up more than a few percent of the total sample.

Where winds have selectively removed low specific gravity minerals from sand, the grain size of the thin veneer or residue of heavy constituents that remains as blacksand is very much finer than that of light-colored surrounding sand on which the winnowing process is not far advanced. Although the products of the winnowing action of prevailing on-shore winds are quite evident at many points on the coastline they are of small volume; production of larger quantities of blacksand by these means was observed particularly in the sand-dunes both to the north and south of the mouth of Pajaro River.

The relative frequencies of the heavy minerals present in a number of representative assemblages after removal of magnetite and ilmenite are shown in table 1 and, by and large, these data are averages of counts of at least 300 grains for each of several preparations from specific localities. For example, the data recorded under "Whitehouse Creek" have been obtained by averaging counts of a total of 400 grains in each of three size-fractions of eight samples from that locality, that were

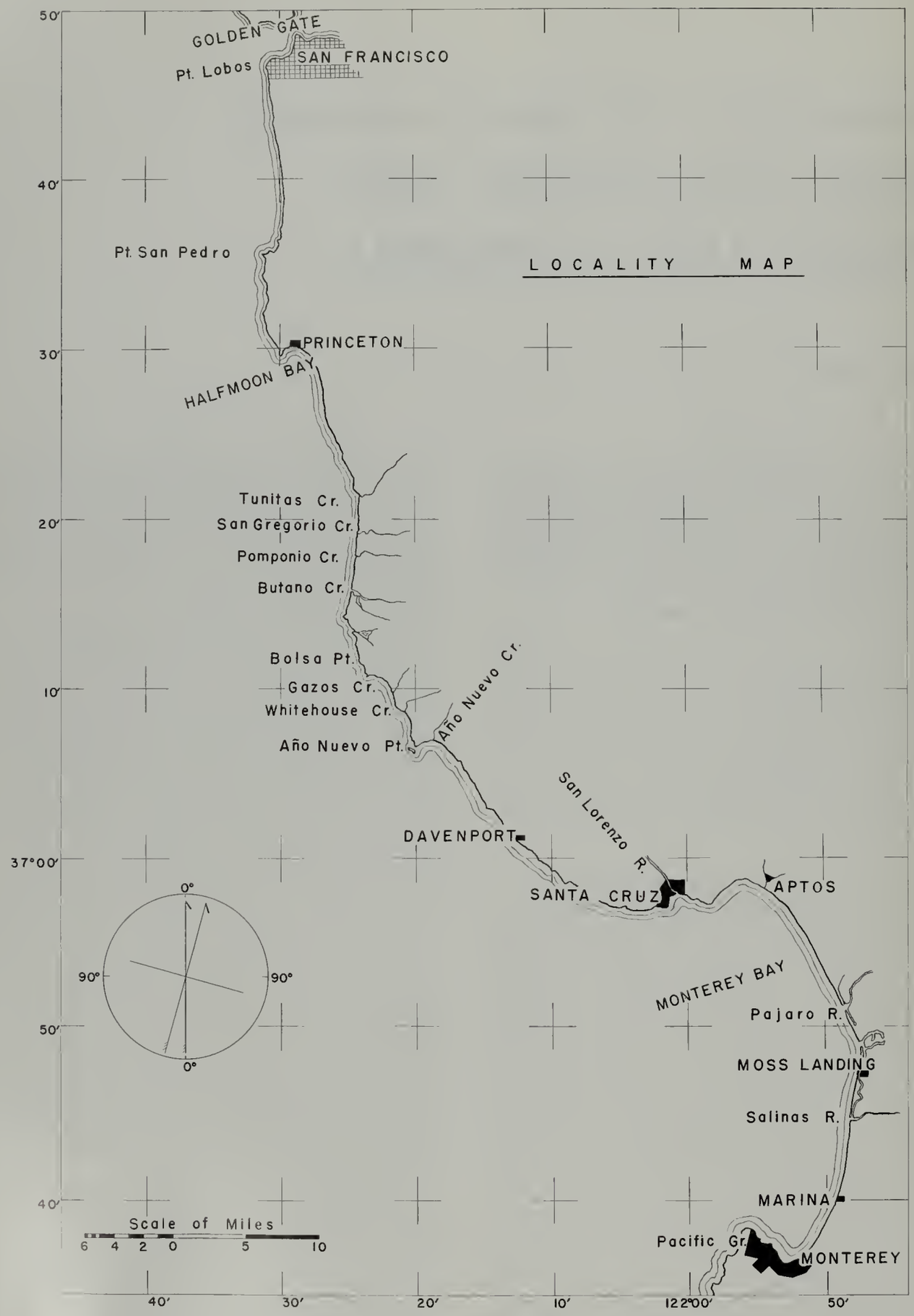

FIGURE 1. Index map of coastline from Golden Gate to Pacific Grove, Monterey peninsula, showing localities specifically mentioned in this report.

collected over a period of 2 years. But for the finest screenings of Whitehouse Creek material, —250 mesh, fewer than 100 mineral grains remained in each case after removal of ferromagnetic (magnetite) and strongly paramagnetic (ilmenite) fractions; hence counts of any significance were not possible. Where at least 300 grains were available for counting, the percentages of the different minerals thus obtained have been expressed in table 1 following the procedure of Evans, Hayman, and Majeed (1934). However, where the number of particles is inadequate to permit satisfactory use of this scale the following system is used:

p = predominant (> 60 percent)
a = abundant (20-59 percent)
fa = fairly abundant (5-19 percent)
m = minor constituent (< 4 percent)
r = rare.

Many samples from localities other than those listed in table 1 were studied, but the grain counts from these have not been included in this table since they add little if anything to the general picture set out in table 1 and figure 3. Magnetite and ilmenite make up much of the heavy fractions and ilmenite, which tends to have larger average grain-diameters than magnetite, is the more abundant constituent in most samples.

FIGURE 2. Histograms of sands and heavy minerals therein. (1) Princeton Beach; (2) Mouth of Tunitas Creek; (3) Mouth of San Gregorio Creek; (4) Mouth of Butano Creek; (5) Mouth of Bolsa Creek; (6) Mouth of Gazos Creek; (7) Mouth of Whitehouse Creek; (8) Mouth of Año Nuevo Creek; (9) Aptos Beach; (10) Mouth of Pajaro River; (11) Marina Beach; (12) Monterey; (13) Pacific Grove.

LOCALITY.	ALLANITE	ANATASE	ANDALUSITE	APATITE	ARAGONITE	AUGITE (GREEN)	AUGITE (BROWN)	BARITE	BIOTITE	BROOKITE	CASSITERITE	CHLORITE	CHROMITE	CHRYSOBERYL	CLINOZOISITE EPIDOTE	COMPOSITE PARTICLES	CORUNDUM	DIAMOND	DUFRENITE	EUXENITE	GARNET (COLORLESS)	GARNET (PINK)	GLAUCONITE	GLAUCOPHANE	GOLD	HORNBLENDE (GREEN)	HORNBLENDE (BROWN)	HORNBLENDE (OXY-TYPE)	HYPERSTHENE	LEUCOXENIC MATERIAL	MONAZITE	MUSCOVITE	OLIVINE	OPAQUE GRAINS	PIEDMONTITE	PUMPELLYITE	PYRITE	RUTILE	SCHEELITE	SPHENE	TANTALITE	THORITE (URANOAN)	TOPAZ	TOURMALINE	VESUVIANITE	XENOTIME	ZIRCON (COLORLESS)	ZIRCON (PINK)	ZOISITE	DOUBTFUL DETERMINATIONS
−250 Mesh.																																																			
PRINCETON Bh.													6		1											1'	1'	1'	1'		1						1'									B-	1		
TUNITAS CREEK					1'	1'	1'															1'				1'	1'				1			6+			1'			1'						B	1		
SAN GREGORIO Cr.	1			1		6				1					5	5								1		6_E	5	4	4				1	5			1'			1'		1'		1'			1			1		—	—
BUTANO CREEK			1'	1		7+				1'					4						2					4	1	1'	3	1'				6				1'			2		1'		1'			4			
BOLSA CREEK						4							4		6			6−			4					7^E	4	1	1'					F						3		1'	1'				4			
GAZOS CREEK				1_A		6−		1'				1'	6+		4	4		1			4				6−	5_E	5	1'	5	2						4					3		1'	1'				4			1'
WHITEHOUSE Cr.						fa							a		r						m					fa			m											r						a			
AÑO NUEVO Cr.	1'	1'		1'		2	2				1'		4		5				1			3		1		5	3	2	1		4		1'				1'	1	1	4		2		1'			7+	2		
APTOS BEACH				1'		4					1'				4						1'					5	1	1	4					1				1'		1				1'				B-	1		
PAJARO RIVER	1'			1		1		4	1	1'					3						1			1'		3		1'	1'		4			6				1'		5		2			1			7+	1		
MARINA BEACH				1		1	5		1	1		1			5							6−				7	1'				4			5				1		4		1				5	1		
PACIFIC GROVE				3		1	5		1	1		1			4							5				6+	6				1			4				1		5						4	1		1
−115+250 Mesh.																																																		
PRINCETON Bh.				1'	1'	4				1'			7−		4	4						1'		1'		6+	2	1	2				1'			1'		1'		4		1'		1'			6	1'	1'	
TUNITAS CREEK				1'		2	1'			1'					2						2	1				3	1'	1'	2		1			7+				1'		3		1'				7	1'	1'	—
SAN GREGORIO Cr.			1'			1'	1'								1	1					2	1				2	1'	1'	1					7+				1'		1						7	1'		
BUTANO CREEK	1'			1'		3	1			1'					1	3					1		1'			3	1	1	3		1'			7+				1'		2		1'				7-	1		
BOLSA CREEK				1'		5	2						6		4	4					4		1'	1		6	4	1	4	1			2							4							6			2
GAZOS CREEK			1'	1'		4		1'							4	1					3			1'		5	3	2	4	1	1'			6		1'		1'		3	2					7	1'		1'
WHITEHOUSE Cr.						1	1						6+		1						1	1				1	1	1	1											1		2					8-	1		
AÑO NUEVO Cr.	1'			1		3	1				1		6-	1	3		1'				1			1'		2	1	1	2		1				1	1			4	1	1'		1'		1'		B-	2	1'	
APTOS BEACH				1		6+	3						5		4	3					2			1'		6-	5	4	6		1'		1'					1'		4		1'				1		1'	
PAJARO RIVER						3	1'	1		1'					1'	1					2_B	1'				3	1	1	2		1		1'							2						2	1'	1'	
MARINA BEACH				1		1	4								2							7				5	5	3	1		3			4				1'		4		1'			1	6-			
PACIFIC GROVE	1'	1'		1			5			1'					3							7				6-	5	2	1'		4			5			2		4			1'		1	6			1'
−60+115 Mesh.																																																	
PRINCETON Bh.		1	1	$1'_A$		2	1'	1'					3		4	5					1'	1'				7+	5	1'	3										4			1'				2		1'	
TUNITAS CREEK				1'		5	5								5	7	1'				3_B	2		1'		6	3	2	5	2	1		1'	6-				1		5			1'			4		1'	2
SAN GREGORIO Cr.	1					5	6								3	6−					2	1				5	3	2	5					5				1'		4					1'	4			
BUTANO CREEK				1'		5	6−								4	6−					2	1				5	4	1'	5					6-						4						5			
BOLSA CREEK						5	5	1'		1'			7		2	5					1	5	1'	1'		1	3	2	4												3		1'					5	1	1'	—
GAZOS CREEK			1'		1	6−	6						5		2	6−					2	1				6−			5	1'			1			1'	1'			2							3		1'	1'
WHITEHOUSE Cr.			1			5	4						7		1	4	1				2	4		1'		4	1	1	5							1'				3	1'					6-	1	1'	
AÑO NUEVO Cr.				1		6	5					1'	5	1'	3	5				1	2	4				4	2	2	6−		1									4		1					2			1
APTOS BEACH			1'	1'		6+	4						2		2	6					1'			1'		6	5	3	5		1'		1							2							1			2
PAJARO RIVER	1'					5	1	1							2	5					2	3				4	4	1	5				1	7						4							4	1'		—
MARINA BEACH				1		1	5		1						1	1						6+				6−	7−	4	1'			1		4				1'		4		1'				3			1
PACIFIC GROVE				1		1	5		2						1	2						6				6-	7	4			1	1		4						4							3			—
−32+60 Mesh.																																																	
TUNITAS CREEK			1		1	6	6								4	6+					1	1				4	1	1	4	3	1'			5_C						1										
SAN GREGORIO Cr.					1_D	6−	7								1	7−										3	3	1'	3				1'	2						1										
BUTANO CREEK						5	7−		1'			1'	2		7						1	1'		1'		3	1	1	1					2						1						1'			
BOLSA CREEK						5	6−					7−	2		7−	1'					4	4				1'		1'	2											1						2			
GAZOS CREEK				1'	1'	5	6					5	2		7−						2	2	1			4	2	1	4	3			2						1'		2						1'			
PAJARO RIVER						6	1'			1'			4		7−						4	4		1'		5_E	4	1'	4	1			1	4						5					1'		1	
MARINA BEACH						1	6		5				1		1							5				6+	4	6+					1							3						3			
PACIFIC GROVE				1		1	6		6−				1		1							6−				6-	4	6+				2					1			4						2			1

A. INCLUDES COLLOPHANE B INCLUDES UVAROVITE. C INCLUDES HEMATITE. D ENTIRELY MAGNESITE. E. INCLUDES TREMOLITE. F ENTIRELY GALENA.

Table 1. Mineral frequencies.

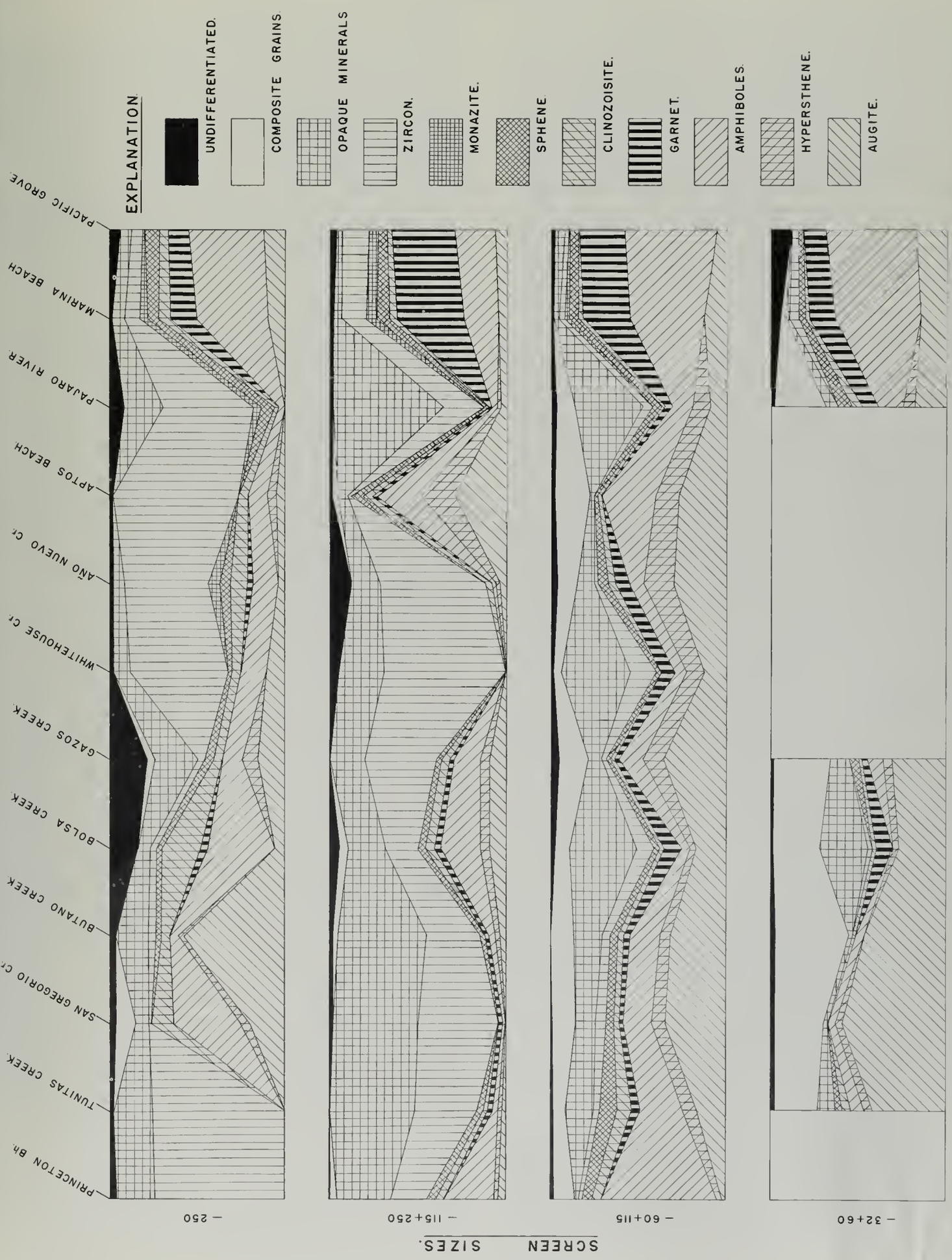

FIGURE 3. Variation of mineral frequencies in sands collected at the localities indicated. Vertical, cumulative percentages; horizontal, sample localities (distances between these points are not to scale).

The light fractions, material with specific gravities less than about 2.88, consist mainly of feldspars, quartz, acid volcanic glass, glauconite (this is found in heavy fractions as well), calcite, composite rock fragments, clay pellets, micas, fragments of both calcareous and siliceous organic remains, and a minor amount of non-mineral matter. Detailed investigation of this material has not been made.

Variation of mineral frequencies, exclusive of those for ilmenite and magnetite, is illustrated in figure 3 which shows the following points:

(1) The effect of introduction of fine-grained augite from the Purisima formation.
(2) Changes due to accession of material from San Lorenzo River that enters the ocean at Santa Cruz just north of Aptos.
(3) Marked change of character of sands south of Salinas River.

ELECTROMAGNETIC FRACTIONATION

Provided the diameter of particles in samples is uniform, the magnetic susceptibility of the particles depends largely on composition. Ironstain on the surface of mineral grains can have considerable effect on their behavior in a magnetic field, and on many occasions, stains on some grains and not on others have permitted selective attraction and concentration, after which the stain has been removed by chemical means. Thus it has become standard practice not to remove ironstain unless, of course, it is excessive, until the last possible moment. Artificial production and selective deposition of metallic iron films on mineral grains followed by electromagnetic fractionation has been utilized in some instances (Vincent, 1951, p. 1074).

The Frantz separator was usually adjusted with a slope of 15° and a tilt of 10°, but before separations were made with it, ferro-magnetic material was removed with a hand electromagnet (Hutton, 1950, p. 644).

The relative order of fractionation of a number of constituents with a particle size range of —0.124 +0.061 mm. follows, but excluded are data on several minerals for which there was too small an amount of material for experimentation:

Fraction 1. Current 0.2 amps:
(a) Ilmenite, martitized magnetite, and other oxides of iron with or without titanium; often heterogeneous in nature.
(b) Iron-rich chrome spinels.
(c) Silicates, chiefly pyroxenes and amphiboles that contain inclusions of magnetite, ilmenite, etc.
(d) Composite particles.
(e) Iron-rich epidote and allanite (Fe_2O_3, 10.25 percent; FeO, 7.33 percent; MnO, 6.74 percent; ThO_2, 0.95 percent). Although only dubiously recognized as constituents of the sands studied, members of the columbite-tantalite series are attracted at about 0.25 amps.; samarskite is attracted at approximately 0.275 amps.

Fraction 2. Current at 0.35 amps:
(a) Chromite.
(b) Less ilmenite than at 0.2 amps.
(c) Green and brown hornblende abundant here.
(d) Pyroxenes, chiefly augite and hypersthene; olivine with 15-20 percent of the fayalite molecule.
(e) Epidote, garnet (spessartite-almandine; n = 1.79-1.80; sp. gr. = about 4.1, chrysoberyl, presence possibly due to inclusions, and inclusion-bearing monazite.
(f) Euxenite; other studies by the writer have shown that members of the euxenite-polycrase, and aeschynite-priorite groups generally, are attracted at 0.35 amps., or very close thereto, although a sample of blomstrandine from Morefjaer, Arendal, Norway was concentrated precisely at 0.31 amps.
(g) Composites.

Fraction 3. Current at 0.45 amps:
(a) Main pyroxene concentrate (composition of the common pyroxene is approximately equivalent to that of augite close to diopside as determined from optical measurements, viz: Wo 49 percent, En 38 percent, Fs 13 percent).
(b) Garnet (spessartite-almandine).
(c) Hornblendes, less abundant than in the previous fraction.
(d) Sphene, monazite, pumpellyite, xenotime.
(e) Minor opaque minerals.
(f) Zircon by reason of inclusions therein.

Fraction 4. Current at 0.75 amps:
(a) Main monazite and sphene fractions. Monazite contained ThO_2 4.22 percent; FeO 0.61 percent; sphene with Al_2O_3 1.44 percent and total iron as FeO 1.23 percent was attracted at 0.60 amps., rejected at 0.55 amps.
(b) Considerable amount of uranoan thorite; dark-colored phase.
(c) Garnet (grossular types).
(d) Zircon by reason of inclusions.
(e) Pyroxenes, amphiboles, opaques, epidotes, all in minor amount.
(f) Composites abundant in specific instances (saussuritic aggregates, etc.).

Fraction 5. Current at 1.2 amps:
(a) Sphene important but less abundant than in fraction 4.
(b) Zircon with minute inclusions.
(c) Uranoan thorite; lighter green than previous fraction.
(d) Grossular, hydrogrossular.
(e) Composites very important in some samples.
(f) Opaque fragments usually rare.
(g) Corundum; andalusite, but erratic in behavior due to frequency of opaque inclusions.

Fraction 6. Fraction rejected at 1.2 amps:
(a) Zircon and apatite are usually the dominant constituents here.
(b) Pale green uranoan thorite.
(c) Rutile, brookite, anatase, cassiterite, scheelite, barite, corundum, diamond.

MINERALOGY OF THE HEAVY MINERALS

Amphibole Group

At least one member of the amphibole group is present in each size fraction of each of the sands studied, although three and even four varieties have been found in many samples. Amphiboles recognized are derived from at least two distinct paragenetic associations: tremolite-actinolite and glaucophane from a metamorphic environment, and brown and oxy-types with which may possibly be grouped a green to brownish-green hornblende, derived from volcanic, or certainly igneous sources. In general the frequency of amphiboles present in the sands shows considerable variation from north to south along the coastline studied and, in general, members of the group are only slightly more abundant in coarser than in finer grade sizes.

Tremolite-Actinolite

Members of this group are rare and occur as minute needle-shaped or ragged fragments of very pale green to bluish-green color with faint pleochroism. For one sample, a — 32 + 60 fraction from a blacksand paystreak three-quarters of a mile south of the mouth of Pajaro River, the following optical data were recorded:

$\alpha = 1.627$
$\gamma = 1.649$
$X =$ very pale green
$Z =$ pale bluish green
$Z \wedge c = 18°$
$2V = 65°$ (–)

The extinction angle Z′ to *c* for what seemed to be fragments resting on (110) was approximately 22°, a value in excess of that found for the (010) plane or the true extinction angle Z to *c*. On the basis of Fresnel's law the extinction angle for an orientation parallel to a cleavage plane when Z to *c* and 2V are 18° and 65° respectively, was found by construction (Duparc and Pearce, 1907) to be 21°. Accordingly it must be stressed that determination of extinction angles must be made with some caution when orientation within the zone [001] is not known exactly. The blue tint in the Z — vibration direction suggests that this amphibole is a member of the actinolite-glaucophane series of Kunitz (1930), but close to the actinolite end since a lavender tint is not evident.

Glaucophanic Amphiboles

Amphiboles that belong to the glaucophane-riebeckite rather than to the actinolite-glaucophane series are fairly widely distributed but in none of the samples examined do they exceed 1 percent of any particular size fraction, and quantity is usually much less than this.

An abraded, but dominantly stumpy, prismatic form is general. Pleochroism with X = colorless, flecked with green, Y = violet, and Z = deep azure blue is usual in spite of variation in other optical properties. Separation of sufficient material for more complete determination was not accomplished except once when the following data were obtained: $\alpha = 1.635 \pm 0.002$; $\gamma = 1.649$; $\gamma - \alpha = 0.014$; $2V = 12°(-)$; $Z \wedge c = 4°$; dispersion $r < v$ strong. The type of dispersion was not recognized with any degree of certainty but the positions of the colored areas in the interference figure relative to the points of the melatopes suggest dispersion of bisectrices, rather than of optic axes. The size of the optic axial angle points to a composition close to crossite, but the amphibole is not that since optic axial plane and clinopinacoid are parallel. Optic axial angles larger than 30 to 50° appear to be more usual, however, and zoned crystals with lighter colored central areas and darker peripheries are not uncommon.

Inclusions are frequent and the following were recognized: quartz, plagioclase (most likely albite), members of the clinozoisite-epidote group, muscovite, stilpnomelane, sphene, pumpellyite (?), apatite; some opaque grains were found, enhancing the magnetic susceptibility of the particles.

Hornblendes

Three distinct varieties of hornblende are present: green, brown, and oxy-types. In general, green varieties are dominant, and brown and oxy- forms much less abundant. Well-rounded particles are particularly common in coarser grained fractions, whereas cleavage fragments with ragged terminations or otherwise irregularly fractured grains are decidedly dominant in the finer, and especially in the finest, grade sizes.

In general terms, hornblendes are attracted at lower field strengths than are pyroxenes, particularly clinopyroxenes, but not always, since pyroxene crystals and fragments are more often contaminated with opaque oxides than are hornblendes. This is particularly true of the —115 +250 fraction from the mouth of Gazos Creek where both clinopyroxenes and hypersthene make up approximately 50 percent of the ilmenite fraction attracted in a weak magnetic field (0.10 amps.). In material collected from a point just south of Pajaro River, both pyroxenes and amphiboles were so contaminated with inclusions of magnetite or ilmenite that they were fractionated together with magnetite in the ferromagnetic portion and also with ilmenite in a slightly stronger field. For crystals devoid of opaque ferruginous and/or titaniferous inclusions, however, pyroxenes are magnetically less susceptible than amphiboles.

In general, inclusions are less frequent in hornblendes than in pyroxenes and where identification could be made they were: iron oxides (magnetite, titanomagnetite, ilmenite, hematite), apatite, quartz, plagioclase, leucoxene (?), and needles of rutile (?).

Solution effects have hampered development of grains with multiple terminating pyramids—the so-called "cockscomb" structures of Ross et al. (1929) and other investigators; in fact, they are decidedly rare compared to similar effects produced in the associated orthorhombic and monoclinic pyroxenes.

Green or Greenish-Brown Amphiboles. Amphiboles belonging to this category are more important constituents of blacksands, paystreaks, and heavy fractions than the sum of other varieties present. In material from Princeton Beach, green or greenish-brown hornblendes constituted 60 percent of the —60 +115 fraction, and percentages in excess of 20 are not uncommon in other samples. No size fraction of any sample studied is free from hornblende of this category.

Optical properties show a range of values and the data that follow give some measure of this:

	Mouth of Año Nuevo Creek	¾ mile south of Pajaro River	Range or other data noted
α	1.654	1.650	1.650–1.662
γ	1.672	1.665	1.665–1.679
$\gamma - \alpha$	0.018	0.015	0.014–0.022
$Z \wedge c$	19°	17°	14–22°
X	yellowish-green	pale green	yellow
Y	olive-green	green	brownish-green
Z	deep green with a tinge of blue	deep green	deep brownish-green (rarely nearly opaque)
Absorption:	Z>Y>X	Z>Y>X	

In some instances green to greenish-brown hornblendes are so deeply colored that they are nearly opaque for the —60 +115 size fraction, and at first sight, these grains differ little from ilmenite when they are viewed in oblique illumination. This is especially so if fragments are well rounded and polished so that prismatic cleavage is not evident.

Undoubted solution effects comparable to those developed in pyroxenes are infrequently found (see Princeton —115 +250 mesh where incipient pyramidal terminations have developed). Zoning due to pre-depositional circumstances was noted in occasional grains, and generally this takes the form of dark green nuclear areas with paler colored or colorless peripheral zones.

Brown amphiboles, generally less abundant than are green varieties, exhibit a range of forms similar to those of the latter, and show complete gradation towards them optically. In a number of instances, as in brown varieties devoid of any reddish tints, pleochroism is not as pronounced as in green hornblendes.

Oxy-Hornblendes. Red-brown amphiboles of the oxyhornblende type are present in most size fractions but in no instance exceed 4½ percent of any fraction and usually are very much less than this. They exhibit a range of forms similar to those found for green and brown amphiboles. Color is typically red-brown and optical data for a wide range of fragments are as follows:

X = brown, yellowish-brown, golden brown.
Y = deep brown.
Z = deep red-brown.
$Z > Y > X$
$2V = 59 - 73°$ (—)
$Z \wedge c$: 2 — 7°, but usually closer to the lower figure (Fedorov stage determinations).

α	1.675*– 1.678
γ	1.740*– 1.747
γ – α	0.062 – 0.069

Anatase

Anatase, recognized as a rare constituent of the finest fraction of blacksand found at the mouth of Año Nuevo Creek, occurs as pale yellow, non-dichroic, rectangular, fractured tablets that exhibit a pattern of parallel striations.

Andalusite

Very well rounded (Princeton) to highly irregular grains (Whitehouse Creek) of andalusite were found in a number of samples, but this constituent is never more than a minor accessory. Inclusions are usually quite numerous, with both opaque and brownish iron oxides predominant but biotite common, whereas in other samples extensive sieving with quartz, feldspar, or biotite was noted. Pleochroism is pronounced and in larger sized fragments, as in the —32 + 60 fraction of Tunitas Creek sand, this characteristic is most marked. For the Tunitas Creek example the following data have been determined.

α = 1.633
γ = 1.644
γ — α = 0.011
X = rose
Z = green

Unfortunately adequate material for manganese and iron determinations was not available, but the intensity of absorption and rather higher refractive indices suggest some degree of replacement of Al^{3+} by Mn^{3+} and/or Fe^{3+}.

Apatite

Although apatite is widely distributed, few fragments are found in most samples, and more than 0.5 percent was not recorded.

Stumpy euhedral prisms that exhibit effects of slight abrasion predominate in finer grade sizes, whereas well rounded fragments are most often met with in coarser screenings. In many cases apatite is free from inclusions, but when these are seen they are usually in the form of lines of cryptocrystalline particles arranged parallel to the vertical crystallographic axis. Such crystals have the appearance of being medium to strongly dichroic in smoky or brown tints, but to what extent this apparent dichroism results from a "wink" effect due to rapid change of the difference of refractive indices between inclusions and apatite host on rotation of the microscope stage, is not clear.

Pale yellow apatite is associated with colorless fragments of the same mineral in one sample (mouth of Año Nuevo Creek), and in a black sand paystreak from the northern end of Princeton Beach, occasional extraordinarily smoothed, egg-shaped grains were recognized. The latter are colorless and water-clear with the longer dimension of the ellipsoidal particle invariably at an angle to the *c* crystallographic axis, that is, to the longer dimension of the original crystal. Such material must result from very long-continued abrasion of initially irregularly shaped fragments, otherwise it is difficult to visualize the way in which crystals of apatite of normal habit could become worn to elliptical forms that do not exhibit some degree of parallelism to the forms of the original crystals. These circumstances are reminiscent of those described for zircon from Slab Hut Dredge, Westland, New Zealand (Hutton, 1950, p. 687).

Collophanie fragments derived from tooth and bone material are generally irregular in shape in finer grade sizes and rounded or much abraded in coarser particles; color is typically pale yellow but shows a range between this and red-brown. Weak anisotropism and cryptocrystalline aggregate structure that does not exhibit definite extinction, are characteristic.

X-ray powder patterns are yielded by single particles of collophane, and although films exhibit no reflections at angles greater than 60° 2 θ, the patterns are otherwise comparable to those of apatite. Measurements in one case gave cell dimensions of $a = 9.33$ Å., $c = 6.88$ Å ± 0.03 Å, or values similar to those recorded for carbonatian fluorapatite.

Aragonite

The orthorhombic form of calcium carbonate has been recognized as an occasional constituent of sands from several localities, and in each instance it forms thin, abraded fragments with aggregate structure; presumably this is shell material. A distinct pleochroism, nearly colorless to pale mauve or purple (Hutton, 1945, p. 300) is usual; however, optic axial angle determinations of 17° and 19° in two fragments with $\gamma = 1.684$ and 1.685 respectively, support diagnosis as aragonite. If this is shell-derived material, and it certainly appears to be so, the data recorded here do not support Bøggild's (1930, p. 237) contention that the optical properties of shell aragonite are not exactly identical with those of aragonite from other natural sources.

Barite

Barite was found in four samples but only in sands near the mouth of Pajaro River is it more than a mineralogical curiosity. Rectangular cleavage fragments of dusty aspect due to clouds of innumerable minute, and colorless indeterminate inclusions are usual. A mottled or blotchy effect comparable to that found in barite of concretions is evident between crossed nicols in some instances; it may result from slight disorientation of

* These values, ± 0.003, were found for a large number of oxytype amphiboles present in the sands.

originally parallel lamellae. An optic axial angle of 38-40° and a value of 1.635 for α supports the conclusion that the mineral has a composition close to that of pure barium sulfate.

Biotite

It is to be expected that micas would not be well represented in mineral assemblages on exposed oceanic beaches but biotite has been recognized in four sands, in which it is usually more abundant in the coarser size fractions. A deep red-brown color with very strong pleochroism is characteristic and, for separated platelets, the following data have been determined:

Aptos Beach:

γ:	1.656,	1.662,	1.664,
2V:	0°	0°	34°
Dispersion –		–	r<v, very strong.

Mouth of Butano Creek:

γ: 1.660, 1.689.

In sands from Pacific Grove, biotite is much more plentiful and deemed worth fuller study. Before analysis the mica concentrate was carefully freed of platelets that contained inclusions of zircon and apatite, and absence of both zirconium and phosphorus in the spectrographic analysis indicated that purification was adequate. The Pacific Grove biotite (analysis 1 table 2)

Table 2. Analyses of biotite.

	1	2	3	4	5
SiO_2	34.98	35.88	34.43	34.62	34.87
TiO_2	3.47	4.17	3.51	2.42	3.21
Al_2O_3	17.06	14.96	17.43	17.63	17.31
Fe_2O_3	9.30	2.33	2.50	4.99	6.48
FeO	14.49	20.88	21.65	18.92	17.56
MnO	0.42	0.18	0.44	trace	0.32
MgO	5.80	10.04	5.88	7.54	6.97
CaO	0.38	0.12	1.22	0.38	0.29
Na_2O	0.39	0.36	0.58	3.09	0.42
K_2O	7.02	9.20	8.83	7.75	8.13
H_2O+105°C.	3.96	0.80	2.56	2.65	3.35
H_2O—105°C.	1.40			0.17	0.57
F.	0.47	1.58	1.12	--	1.38
	99.14	100.50	100.29	100.16	100.86
Less O for F	0.19	0.66	0.47	--	0.58
	98.95	99.84	99.82	100.16	100.28

1. Biotite from sands, Del Monte Properties, Pacific Grove, Monterey Co., California. Analyst: Atomic Energy Commission Chemical Laboratory, analysis 4453-A. Silica corrected for fluorine.
2. Biotite from monzodiorite, Belknap Mts. (Chapman and Williams, 1935, p 512, Table 7, anal. no. 2).
3. Biotite from dark vein in granite, Widecombe, Dartmoor. See Nockolds, 1947, p. 406, Table 2, anal. 17. Summation includes 0.14 percent Li_2O.
4. Biotite from gneiss, Tomanowa Valley, Poland (Zastawniak, 1951).
5. Biotite from Jamesburg, Carmel Valley, California. Analyst: C. Osborne Hutton.

is iron-rich, relatively low in magnesia, but comparable in many respects with the micas listed in columns 2-5, inclusive, in that titanium, total iron, and alumina are similar. In addition, the optical properties are similar to those of the mica represented by analysis 2 (table 2).

Recalculation of the biotite analysis on the basis of the formula $(O.OH.F)_2\ W(X.Y)_{2-3}\ [Si_4O_{10}]$ (Strunz, 1949, p. 212), set out in table 3, makes it clear that a considerable amount of Al^{3+} must be grouped with Si^{4+} in order to bring the tetrahedrally coordinated group to four as is required structurally. Titanium has been included with six-coordinated metals on the basis that the Ti^{4+} — O^{2-} radius ratio is better suited to six rather than to four coordination. However it should be borne in mind that if Ti^{4+} is grouped with Si^{4+} in this instance, Al^{3+} would have to be adjusted to permit only 1.111 atoms to

Table 3. Recalculation of analysis of biotite from Pacific Grove.

	Wt. percent	Oxygen	Metals		
SiO_2	34.98	1.165	2.689	1.311	4.00
Al_2O_3	17.06	.502	1.544		
TiO_2	3.47	.087	.200	.233	
Fe_2O_3	9.30	.175	.536		
FeO	14.49	.202	.931		2.591
MnO	0.42	.006	.027		
MgO	5.80	.144	.664		
CaO	0.38	.007	.031		
Na_2O	0.39	.006	.058		0.777
K_2O	7.02	.074	.688		
H_2O	3.96	.220	2.030		2.144
F	0.47	.012	.114		

This leads to the formula:

$$(OH,F)_{2.14}\ (K,Na,Ca)_{.78}\ (Mg,Mn,Fe^{2+},Fe^{3+},Al,Ti)_{2.59}\ [(Si,Al)_4O_{10}]$$

enter the tetrahedrally linked sheets, the remainder in six-coordination. The question of the position of Ti^{4+} cannot be unambiguously settled here, but it should be remembered that similar difficulties arise in distribution of Ti^{4+} in titaniferous augites low in Fe^{3+} and Al^{3+}. In such cases where the combined Si^{4+} and Al^{3+} is insufficient to satisfy the requirements of pyroxene structure, there appears to be no alternative but that Ti^{4+} may replace Si^{4+} (Dixon and Kennedy, 1933; Deer and Wager, 1938).

If Ti^{4+} is grouped with the cations of coordination number 6, then Al^{3+} in the Pacific Grove biotite is dominantly tetrahedrally linked with only a small amount remaining to replace X and Y group cations. This division of Al^{3+} is found in biotites from igneous rocks devoid of muscovite in which biotite tends to be the sole mafic constituent or those in which minor hornblende may also be present (Nockolds, 1947). Certainly the granites which crop out in the vicinity, the source rocks of the mica described here, may be so described, in that they are generally devoid of muscovite and hornblende.

The figure of 0.78 for the large ions Ca^{2+}, Na^+, and K^+ is unsatisfactory and suggests that the analytical determination of alkalis may be in error. On the other hand, the relatively high figure for H_2O — 105° C. would tend to suggest that the mica has undergone some alteration; this may also be a reason for the deficiency in the W— group.

Spectrographic determinations on the Monterey biotite are as follows:

>10 percent	Al, Fe, Mg, Si
1-10	Ti
0.1-1.0	Ca, K(?), Mn, Na
0.01-0.1	Ba, Pb, Zn
0.001-0.01	B, Cu, V
<0.00$_1$	Ag, Cr, Mo, Sn
Not detected	As, Bi, Cd, Co, Ga, Ge, In, Ni, P, Pt, Sb, Ta, Th, U, W, Y, Zr.

Physical properties for the analyzed biotite are:

$\alpha = 1.610 \pm 0.004$
$\gamma = 1.665 \pm 0.002$
$\gamma\text{-}\alpha = 0.055$
X = yellow
Y = Z dark brown
X < Y = Z

Dispersion strong with r < v.
2V = 0 — 20°; generally 8 — 12°.
sp. gr. at 22°C. 3.04 — 3.09; generally 3.06 ± 0.01

Brookite

Brookite is a rare but fairly constant constituent of finer fractions of many sands, and is almost invariably found concentrated in the non-magnetic fraction * associated with zircon, cassiterite, apatite, rutile, etc.

It forms equidimensional sub-euhedral to euhedral grains that appear to be tabular parallel to (010), since a high proportion of grains exhibit Z perpendicular thereto (Palache et al. 1946, p. 560). Color by transmitted light is pale yellow, but in oblique illumination it is brownish-yellow with a rather waxy or greasy luster (cf. rutile). Pleochroism is faint but distinct for orientation perpendicular to Z, with the direction perpendicular to the striae pale yellow, and yellow parallel thereto.

In blue light 2V is small and the optic axial plane is parallel to the striae, whereas in red light 2V is distinctly larger and the optic axial plane is perpendicular to the *c* axis, assuming that the striae are parallel to that axis.

Cassiterite

Cassiterite has been recognized with certainty in the finer fractions of samples from Aptos Beach and the mouth of Año Nuevo Creek, as anhedral particles of highly irregular shapes and pronounced conchoidal fractures. Brown grains, with blotchy distribution of color and weak dichroism are usual but here and there fragments that give positive tests for tantalum with tannin, and exhibit strong dichroism, colorless (O) to deep blood-red (E), were found. Some twinning was developed, and in such fragments dichroism is much more evident, owing to juxtaposition of two distinct tints across the composition plane.

Chlorite

Chlorite was recorded as a rare accessory in three examples and it is to be expected that individual flakes of members of this group, as distinct from composite grains containing chlorites, such as sanssurite, schist fragments, etc., would be poorly represented in sands on open beaches. From the finest fraction of sand from the mouth of Gazos Creek occasional flakelets of pale green, optically negative, chlorite were separated and determined to have refractive indices very slightly less than 1.64, but this figure was not accurately determined owing to lack of material; however, one of the iron-rich chlorites appears to be indicated.

Chromite

Chromite and chromian spinels will be considered under the heading of opaque minerals.

Chrysoberyl

Some of the occasional colorless fragments of chrysoberyl noted in the assemblages of sands from near the mouth of Año Nuevo and Butano Creeks were well rounded, others irregular with conchoidal fractures, and either water-clear or semi-translucent owing to myriads of dust-like inclusions. Rare fragments exhibit repeated twinning with well marked striations parallel to the periphery *; for such crystals the following data were found: $\alpha = 1.739 \pm 0.003$, $\gamma = 1.747$, $\gamma - \alpha = 0.008$. These refractive indices are distinctly lower than those recorded for chrysoberyl by Winchell (1951, p. 89), but somewhat higher than data obtained for synthetic chrysoberyl by Geller (1941, p. 564), *viz.* $\alpha = 1.732$, $\gamma = 1.741$. In a fragment of a multiply twinned crystal the optic axial angle ranged from 40-55° (+), whereas in other particles 45-60° (+) was noted.

Clinozoisite-Epidote

Members of the epidote group are widely represented and the Al-Fe members of the epidote series are particularly common, with piedmontite rare. Zoisite is a minor constituent but widely distributed, whereas allanite, the only member of the allanite series recorded, is uncommon.

Epidote Series. Epidote and clinozoisite are grouped together, owing to the difficulty of distinguishing between them when the composition is close to that of non-ferriferous members, without recourse to time-consuming refractive index determinations. Distinction is also rendered more troublesome by notable and rapid movement of the ellipsoid, movement that does not seem to be entirely dependent on compositional change, (Johnson, 1949, pp. 506-515).

Clinozoisite-epidote is ubiquitous in each size fraction with slightly greater frequency in finer grade sizes. Fragments are mainly anhedral and conchoidally fractured, colorless with slate blue anomalous tints in the finest size, but pale yellow to greenish yellow with high order colors in coarser fragments. Pleochroism is often evident in particles of large size, or in iron-rich varieties. Refractive indices for the Y-vibration direction lie between 1.740-1.752 in fragments tested; this is equivalent to approximately 8-12% of Fe_2O_3 in the molecule. In the —60 + 115 fraction of material from near the mouth of Whitehouse Creek, however, rounded cleavage fragments of clinozoisite were found with faint, but striking pleochroism, X = pale yellow, Y = pale blue, Z = pale yellow, Y > X = Z. These characteristics are suggestive of pumpellyite, but other optical data (c.f. Johnson, 1949, Table 4, p. 514, last column), definitely point to clinozoisite; these are: $\alpha = 1.720$, $\beta = 1.724$, $\gamma = 1.735$, $\gamma - \alpha = 0.015$, $2V = 90°$ (±), r < v distinct.

Inclusions are frequent and clouds of dust-like particles of iron oxides are particularly well represented in clinozoisitic or iron-poor varieties.

Zoisite. The orthorhombic dimorph of clinozoisite is rather widely distributed as clear colorless anhedra with occasional inclusions of opaque oxides. These fragments often show preferred orientation in mounting media so that centered or very nearly centered interference figures may be obtained therefrom.

α-zoisite, much less common than the β-variety, is recognized by parallelism of the optic axial plane and (010) cleavage, and by strong dispersion with r < v

* Rejected at 1.2 amps. when the isodynamic separator is set at a slope of 10° and a tilt of 8°.

* Comparable, to some extent, to the crystals figured by Berthois (1935), pl. 4, figs. 1 and 2).

(Bolsa Point material). The β-variety shows a range of 2V (0-20°) with r > v. When 2V is very small, the mineral is almost uniaxial in blue light but in red light the optic plane is perpendicular to the cleavage (Princeton Beach).

Allanite: Occasional fragments of non-metamict allanite were found in several beach sands, but never did it exceed 0.5 percent of any size fraction. The habit ranges from well-rounded almost spherical forms to sharply angular fragments with pronounced conchoidal fracture surfaces. Prismatic crystals are not common, but in the few instances where such forms could be recognized, the longer dimension was determined to be parallel to the Y vibration direction.

In each instance color is characteristically a deep brown and pleochroism is intense as follows: X = pale yellow, golden yellow (in thin edges) to pale yellowish brown; Z = very deep brown; almost opaque. A negative optic sign was definitely determined in two instances (Año Nuevo, Butano), and a positive sign observed for material in the −60 + 115 fraction of sand from the mouth of San Gregorio Creek. The size of 2V was not readily estimated due partly to intense color but for grains from near the mouth of Butano Creek a very small angle, approximately 10-20°, was noted and very pronounced dispersion was apparent.

The following data were determined for two separate occurrences:

	Año Nuevo Creek	Butano Creek
α	= 1.785	1.780
γ	= 1.816	1.812
γ-α	= 0.031	0.032
Sp. Gr. (22° C.)	= 3.89 ± 0.02	3.90 ± 0.02

Both samples are readily soluble in hot concentrated HCl, and oxidation of nitric acid solutions by bismuthate indicated the presence of considerable manganese (cf. allanite from Yosemite National Park, California, Hutton, 1951).

Piedmontite: A few prismatic, pale-colored fragments of the manganiferous epidote, piedmontite, were recognized in material from near the mouth of Año Nuevo Creek, but elsewhere the grains are parti-colored with pronounced zonary bands parallel to the length of the fragments, that is, parallel to the *b* crystallographic axis. Pleochroism is weak but distinct as follows:

X = pale yellow
Y = pale purple
Z = violet
Z ⩾ X ⩾ Y.

Birefringence, and refractive index for the Y-vibration direction, are approximately 0.015 and 1.725 respectively. These data taken together with the relatively weak absorption suggest a variety low in both Fe^{3+} and Mn^{3+}.

Composite Particles

Rock fragments and other mineral aggregates are present in every sample so far studied, and in coarser screenings they often rank among the more important constituents and in some fractions as dominant ones. No attempt has been made here to differentiate between distinct varieties of composite material for counting purposes, but instead any detailed identification has been made for the sole purpose of elucidating provinance.

The following mineral associations and rocks constitute the bulk of the heterogeneous material:

(1) Very fine-grained quartz-clinozoisite (or epidote) aggregates with distinctive white porcellaneous aspect in oblique illumination, and semi-translucent appearance in transmitted light.

(2) Excessively fine-grained semi-opaque particles that are white, cream, or grey in color and have a polished ceramic-like appearance in oblique illumination. Quantitatively it can be shown that these consist chiefly of SiO_2, Al_2O_3, TiO_2, and H_2O, and therefore they are thought to be aggregates of clays and leucoxenic materials (rutile or anatase).

(3) Fragments of saussuritic material or quartz-feldspar-epidote aggregates; some carbonates may be present. Particles are usually well rounded, with smooth surfaces and cream to pale yellowish mottled coloration in oblique illumination.

(4) Aggregates of very fine-grained glaucophanic amphiboles and epidote; greenish hornblende is sometimes present instead of glaucophane.

(5) Deep green, well rounded pumpellyite-plagioclase aggregates; in some instances chlorites are present. Also rounded, almost spherical grains of deep green color composed solely of aggregated needles of pumpellyite.

(6) Epidote or clinozoisite aggregates that are pale green in oblique illumination.

(7) Fragments of slightly altered andesite or basaltic rocks, the individual constituents of which can be readily identified in the powder obtained by crushing these composite particles in appropriate refractive index liquids.

Corundum

Occasional grains of corundum have been recognized as rounded, sometimes chipped, anhedra that are colorless or very pale blue, often with irregular distribution of color. The frequency with which centered interference figures were obtained suggests development of basal parting.

Diamond

Diamond is a mineralogical curiosity in two samples, and in one of them—sand from a point 220 yards north of Bolsa Point—constituted 17 percent of the finest fraction.* Characteristically it takes the form of highly irregular fragments with most pronounced conchoidal fractures, or as cleavage fragments of triangular outline. These particles have been referred to as diamond on the basis of the following tests:

(1) The material is quite unaffected by ten minutes immersion in molten potassium pyrosulfate.

(2) Specific gravities of two fragments were found to be very close to that of Clerici solution of density 3.5.

(3) Refractive index is approximately equal to that of a selenium—sulfur glass in which the ratio of Se:S is 3:1.

(4) The fragments are completely isotropic with a distinctive white glimmer when viewed between crossed nicols; quite clearly the glimmer is not weak double refraction since illumination and darkness were not reproducible for 90° rotations of the stage, but this illumination could be completely reduced by preventing any incident light from above from reaching the fragments of diamond. Presumably then, the excessively high refractive index and extreme angularity of the mineral permitted much obliquely incident, yet weak light, to be reflected and refracted into the axis of the microscope.

Dufrenite

The occasional recognition of soft minerals in beach sands, such as those of the dufrenite group, was unexpected and therefore some pains were taken to check the identity of the mineral in question.

* This fraction amounted to 0.03 percent of the original sand.

Tabular, irregularly shaped fragments have a singular aspect due to anomalous interference tints and complete absence of extinction, while pronounced preferred orientation of grains provides more or less centered, strongly dispersed acute bisectrix figures. The following optical properties have been determined for material in sands from near the mouth of Año Nuevo Creek: $\alpha = 1.792 \pm 0.003$, $\beta = 1.800$, $\gamma = 1.845$, $\gamma - \alpha = 0.053$, $2V = 35 - 40°$ (+); dispersion is very strong with $r > v$; X = bluish green, Y = green, Z = deep brown. Absorption for Z is barely greater than that for Y, but is distinctly greater than for X.

These refractive indices are somewhat less than those determined for carefully verified varieties of the dufrenite-rockbridgeite group (Frondel, 1949), or for frondelite and members of the frondelite-roekbridgeite series (Lindberg, 1949), but higher than those for beraunite, a dufrenite-like mineral with large optic axial angle and distinctive pleochroism (Frondel, 1949, pp. 536-539). In the absence of X-ray powder patterns, however, any attempt to be more specific, other than listing the mineral as a member of the dufrenite group, is inadvisable.

Garnet

Garnet has been recognized in almost every size fraction of every sample that has been studied carefully, and three distinct varieties of garnet have been determined—grossular and hydrogrossular, spessartite-almandine, and very rare uvarovite.

Grossular and Hydrogrossular. Grossular is invariably found in forms ranging from well rounded to conchoidally bounded fragments, that are either strictly isotropic or exhibit marked but weak birefringence. Many fragments are dusted through with fine ferriferous inclusions that considerably enhance their magnetic susceptibility, whereas others enclose bands of irregularly shaped colorless isotropic, unidentified particles of low refractive index, relative to that of the host. Occasional grains exhibit features, similar to those produced by repeated twinning, that may have been caused by deformation.

A refractive index of approximately 1.742 was determined for a number of fragments but in one determination fragments with a specific gravity 3.45 gave a low refractive index value of 1.728; for this material positive biaxial figures with $2V = 10\text{-}15°$ were obtained. These data are suggestive of a garnetoid such as hydrogrossular (Hutton, 1943). Such fragments do not show evidence of solution but absence of reports of hydrogrossular in sediments is interesting especially when the work of Flint and Wells (1941) is taken into consideration. These authors have shown that tricalcium aluminate hexahydrate is unstable in solutions that contain Na_2SO_4 when it may be replaced by the "high-sulfate form" of calcium sulfoaluminate. If, on the other hand, the aluminate contains some silica as in hydrogrossular, or Fe_2O_3, the stability is enormously increased. Unfortunately the stability of grossular compared with that of a hydrogarnet like plazolite was not studied, but the lack of occurrences of hydrogrossular as a constituent of sediments and its rarity otherwise, may be connected with a decrease in stability of members of the tricalcium aluminate hexahydrate-grossular system with increase in water percentage. Thus a low-silica form of hydrogarnet in a sediment or associated with gabbroic or ultrabasic rocks may perhaps be removed relatively rapidly in solution, or alternatively converted to the more stable grossular by reaction with siliceous material (Flint and Wells, 1941, pp. 177-8).

Table 4. Physical properties of garnet.

Locality	Color	Refractive index	Remarks
Small bay, 440 yards W. of mouth of Whitehouse Creek	Pale red	1.809	
	Pale pink with paler periphery	1.799	Contained inclusions of gas.
	Very palest pink	1.795	
	Salmon pink	1.795	Colorless needlelike inclusions. R. I. > garnet.
	Pale brown center	1.794	Zoned crystal
	Paler brown periphery	1.797	
	Very palest pink	1.789	
	Almost colorless	1.790	
	Almost colorless	1.792	
	Very pale brownish pink	1.789	
	Deep red	1.810	Regular skeletal arrangements of rutile needles.
	Brown	1.809	
	Very pale pink	1.788	
Mouth of Gazos Creek	Very pale pink	1.794	Sp. Gr. = 3.97
	Deep salmon pink	1.801	Sp. Gr. = 4.10
Mouth of Año Nuevo Creek	Colorless	1.760	Possibly high in grossular molecule.
	Deep pink	1.795-1.800	
	Colorless	1.770-1.780	$2V = 30\text{-}40°$ (+) $\gamma - \alpha = 0.003$; possibly close to grossular.

In material from the mouth of Año Nuevo Creek, rounded fragments with the following rather distinctive properties were found: refractive indices ranged from 1.770-1.780 with birefringence not in excess of 0.003-0.004; good biaxial interference figures; $2V = 30\text{-}40°$ (+); and in one fragment myriads of transparent colorless, unidentified needles intersecting at about 60° are arranged in skeletal fashion. With the small amount of material available Ca^{2+}, Al^{3+}, Fe^{3+}, and Si^{4+} were found. The optical and chemical data suggest a member of the grossular-andradite series, close to the grossular end.

Spessartite-Almandine. Garnet that ranges in color from nearly colorless through pale pink, and deep salmon to brown is believed to be spessartite-almandine; it is found in almost all samples and exhibits a wide variety of grain shapes. Well rounded or sharply angular fragments are general, particularly so in fractions of larger grain-sizes, although there is every gradation between such forms and euhedra that display dominance of *d* {110}, with *n* {211} less often developed. In the $-60 + 115$ fraction of material from the mouth of Gazos Creek very occasional crystals were seen with *a* {100} dominant, the corners of which are slightly modified, possibly by development of *o* {111}, but some degree of abrasion makes definite recognition of the modification uncertain.

Refractive index and specific gravity determinations for a number of examples are set out in table 4 with some additional information. Zoning is frequently developed but, generally, it was impossible to measure accurately refractive indices of different zones, except in a case when this property showed insignificant range. In many instances between the outer border of the homogeneous central area and the outer border of the grain itself, numerous hair-like, concentric zones were seen, which were made obvious only by distinct differences in refractive index between adjoining zones.

Uvarovite. Occasional subrounded grains with $n = 1.83$ and specific gravity = 3.85, found in material from near the mouth of Pajaro River and elsewhere, have been identified as uvarovite. Heating had no effect on these properties (compare gadolinite).

Glauconite

Glauconite is uncommon and its presence in heavy residues appears to result from admixture with minute opaque grains, presumably an oxide or hydroxide of iron, which confers upon the glauconite pellets a specific gravity that is higher than normal and a greater than average magnetic susceptibility.

Gold

Gold has been detected with certainty in only the finest fraction of material from the mouth of Gazos Creek where it ranks as one of the more plentiful constituents of the mineral assemblage. Nevertheless since the finest fraction constitutes only 0.56 percent of the total unfractionated sample, gold is of less importance in this sand than it would appear to be at first sight.

The metal is found as paper-thin irregular flakelets of characteristic color that are soluble in neither concentrated HNO_3 nor HCl; a solution of the metal gave a brownish-red crystalline precipitate with pyridine in hydrobromic acid.

Leucoxenic Material

Leucoxene, recognized in many sands, does not constituate more than 3 percent of any size fraction. It occurs as sub-rounded to rounded pellets that are semi-translucent, buff to white in transmitted light but porcellanous in oblique illumination; high refractive index and birefringence are general and a specific gravity of 3.9 ± 0.1 at 20°C. was determined for a few fragments. Inadequacy of material prevented determination of actual composition beyond showing that Ti^{4+} appeared to be the main constituent.

X-ray diffraction powder patterns yielded by three typical particles correspond exactly in *d*-spacings and intensities to those expected for anatase. Furthermore, the specimens prepared for diffraction consisted of particles 0.05-0.1 mm in diameter—not powdered material—and in spite of this, the films exhibited perfect powder arcs without any trace of spottiness. On the other hand, no indications of line broadening are evident. Accordingly, the range of diameters of crystallites within each of the particles mounted for X-ray diffraction must be approximately 10^{-3} to 5×10^{-5} cm.

These data demonstrate once more that much leucoxene is anatase (Tyler and Marsden, 1938; Hutton, 1950; Broughton et al. 1950).

Magnesite

Colorless rhombohedral cleavage fragments of magnesite were recognized in the —32 +60 fraction of material from the mouth of San Gregorio Creek. The particles, soluble with effervescence in boiling concentrated hydrochloric acid, have the following refractive indices: $n_E = 1.514$; $n_O = 1.706$; $n_O - n_E = 0.192$. These data indicate a composition close to that of breunnerite.

Monazite

The cerium phosphate, monazite, has been recognized in many samples as subeuhedral tablets flattened parallel to *a* {100}. Fragments of similar habit but sharply bounded by (001) and (010) cleavage surfaces also occur, together with occasional basal cleavage fragments which are easily recognized, owing to low birefringence and nearly centered acute bisectrix interference figures. In thin sections of monazite concentrates embedded in plastic, cleavage planes are much more obvious and in some instances the (010) cleavage is distinctly better developed than that parallel to (100); the identity of each of these cleavage directions may be fixed by its position relative to that of the optic axial plane.

Inclusions are not abundant but give to otherwise clear grains a dusty aspect when viewed at low magnifications. The following occluded substances have been observed:

(1) Brown semi-opaque material without definite outline, and irregularly distributed. This may be penetrative iron-stain since it is readily removed by acid treatment of more or less finely crushed crystals.

(2) Aggregates of semi-opaque, isotropic particles of various shades of dark brown; these are unidentified.

(3) Colorless acicular crystals with very much lower refractive indices than those of the host itself. These may be apatite, since a centrifuged fraction obtained from crushed monazite contained this mineral. A number of these needle-like crystals associated with the brown aggregates show some degree of parallelism to the vertical cleavage.

(4) Brown colored zones at the center of crystals from which radiate out a few irregular cracks.

(5) Opaque iron oxides that increase the magnetic susceptibility of the host.

Monazite, from blacksands immediately south of the mouth of Año Nuevo Creek and from white beach sands at Pacific Grove, has been separated in the pure state, first by screening—since it is largely concentrated in the finer size fractions—followed by repeated electromagnetic fractionation, and finally by hand-picking with a very fine-pointed dissecting needle. Analyses of these minerals are shown in table 5 along with determinations of physical data.

The two monazites are similar chemically and optically and attention may be drawn to the following:

(1) Replacement of Ce^{3+} et al. by Th^{4+} is quite small in each case and the upset in electrical neutrality is reasonably well balanced by substitution of P^{5+} by Si^{4+} in tetrahedral coordination. This is clearly seen in Table 6 where recalculation of analysis no. 2, table 5 on the basis of 16 oxygen atoms to the unit cell is shown. There is very slight overall departure from the theoretical ratio for rare earths to P_2O_5, but, since the sample prepared for analysis was purified with the greatest care and inclusion-bearing crystals had been removed, no explanation except inaccuracies in analytical procedure can be offered now to account for this.

(2) An appreciable amount of copper is present in the Año Nuevo mineral, but it is not clear whether this may or may not be an abnormal feature, since comparative data are unavailable. In uranoan thorite associated with this particular monazite, however, analysis shows that 0.11 percent of CuO is present.

Table 5. Analyses and optical properties of monazite.

	1	2
Ce_2O_3 etc.	64.8	63.9
Y_2O_3	see footnote	1.1
ThO_2	3.49	3.9
U_3O_8	0.25	0.2
Fe_2O_3	0.11	0.2
Al_2O_3	nt.dt.	0.15
TiO_2	0.04	0.04
MnO	nt.dt.	trace
Cu	0.007	0.09 (CuO)
Pb	0.018	< 0.01
CaO	0.47	0.7
MgO	nt.dt.	0.1
P_2O_5	28.37	28.5
SiO_2	0.81	0.9
H_2O —	0.35	0.15
H_2O +		nil (?)
	98.715	99.84
U	0.21	--
Th	3.067	--
Pb	0.018	--
Age	106×10^6 years *	
α	1.787 ± 0.002	1.788 ± 0.002
γ	1.840	1.842
$\gamma - \alpha$	0.053	0.054
2V	13° ± 2°	13° ± 2°
Specific gravity at 22° C.	5.21 ± 0.02	5.21 ± 0.02
Dispersion	r < v, distinct	r < v, distinct

1. Monazite from sands, Del Monte Properties, Pacific Grove, Monterey County, California. In addition, the analyst reports as follows: Zr probably <0.01 percent; Cb-Ta not detected; yttrium group 0.5-1.0 percent; U_3O_8 was determined colorimetrically to be 0.25 percent and polarographically 0.24 percent; both Pb and Cu were determined polarographically. Analyst: Atomic Energy Commission Chemical Laboratory Analysis 4453-B.

2. Monazite separated from blacksand paystreaks situated at storm level on beach immediately south of the mouth of Ano Nuevo Creek. No reaction for Ta or Cb was obtained with tannin. Analyst: C. Osborne Hutton.

* Curtis, Evernden, and Lipson (1958, p. 9), who employed the potassium-argon method, have determined the ages of the Montara quartz diorite and the Santa Lucia granodiorite to be 91.6×10^6 and 81.6×10^6 years respectively.

Table 6. Recalculation of analysis of Año Nuevo Creek monazite.

	Wt.%*	Oxygens	Metals	
Ce_2O_3	63.9	.5862	3.708	
Y_2O_3	1.1	.0144	.091	
ThO_2	3.9	.0294	.139	
Fe_2O_3	0.2	.0036	.022	4.12
Al_2O_3	0.15	.0042	.025	
CaO	0.7	.0125	.118	
MgO	0.1	.0025	.023	
P_2O_5	28.5	1.0035	3.808	3.95
SiO_2	0.9	.0300	.142	

* U, Ti, and Cu are omitted since the amounts of each are of little significance.

A spectrographic analysis of the Pacific Grove material made by the Atomic Energy Commission chemical laboratory is set out in table 7.

Table 7. Spectrographic analysis of Pacific Grove monazite.

>10 percent	Ce, La, P.
1–10 percent	Si, Th, Y, Zr.*
0.1–1.0 percent	Ca, Yb (?).
0.01–0.1 percent	Al, Mg.
0.001–0.01 percent	Fe, Pb.
<0.001 percent	Cu.
not detected	Ag, As, B, Ba, Bi, Cd, Co, Cr, Ga, Ge, In, Mn, Mo, Ni, Pt, Sb, Sn, Ta, Ti, U, V, W, Zn.

* The Zr content was estimated but could not be determined accurately.

Olivine

A small number of anhedral and conchoidally fractured grains of olivine, free from serpentinization, has been found in a few samples. The fragments of this mineral are similar to those of colorless diopsidie augite but were distinguished therefrom by the lower refractive indices, higher birefringence, and larger optic axial angle of the former.

Opaque Constituents *

Non-translucent mineral grains are usually the dominant constituents of the paystreaks and heavy mineral fractions studied and in the majority of sands are most plentiful in the —115 +250 size fractions. Particles range from sharply euhedral to most irregularly or conchoidally rounded forms. It has been stressed elsewhere (Hutton, 1950, p. 670) that the difficulties involved in rapidly and positively identifying opaque or semi-opaque fragments are considerable, and little progress has been made in devising new methods or techniques that might expedite such work. It has been found useful, however, to separate opaque or semi-translucent material into fractions carefully by electromagnetic means. In general this will segregate magnetite, titanomagnetite, ilmenite, chromite, martite, hematite, galena, and so on, but with some of these recognizable constituents are others that, although not satisfactorily identified, will be described in the hope that others may find use for the data.

In addition to wide field, binocular microscopic methods, and oblique illumination by white or ultraviolet light of approximately 2540Å and 3660Å wavelengths, the following three techniques were used:

(1) In chromatographic methods, if a small quantity of undetermined fragmentary material is mixed in plastic or bakelite and a polished surface prepared, this surface when placed in close contact with a thin gelatin-coated layer ** that has been saturated with appropriate reagents will develop colored areas in those parts of the gelatin surfaces that immediately adjoin the reacting mineral surfaces. For instance, the presence of titanium may be verified in magnetite by pressing a polished surface, as prepared above, against a gelatin surface that has been saturated with 5 percent solution of chromatropic acid to which some sulfuric or hydrochloric acid has been added. If titanium is present, a reddish-brown coloration will develop. The effect of iron may be suppressed by addition of stannous chloride or phosphoric acid. Alternatively, fine fragments may be scattered carefully and evenly on chemically treated gelatin-coated surfaces backed by paper; in this case rings or haloes of reaction are produced surrounding each reacting fragment. The polished surface used for the detection of titanium may now be used to determine whether vanadium is present in the magnetite by placing the polished surface in contact with a gelatin layer saturated with tannin and dilute hydrochloric acid; iron may be suppressed with phosphoric acid as before.

This technique follows, in the main, the chromatographic print methods set out by Gutzeit (1942), and elaborated later by Williams and Nakhla (1951) and can be successfully employed only with minerals that are not

* Owing to opacity of many minerals except in thinnest splinters, diagnosis and grain-counting may not always be correct, and the figures given in the "Opaque grains" column in table 1 may include chromite, even though a separate figure is quoted for that mineral. Thus, in making comparisons between sands the reader may prefer to combine the figures given for "Chromite" and "Opaque grains". Figures in the "Opaque grains" column exclude both magnetite and ilmenite.

** The writer has employed gelatin-coated glass and paper, which may be prepared from standard unexposed photographic negatives and printing paper by removing silver in sodium thiosulphate and then washing thoroughly.

unduly resistant to reaction with the usual attacking reagents—KCN, NH_4OH, HCl, HNO_3, H_2SO_4, etc. Since particles in a plastic mount are separated from each other, there is no electrical conductivity between them and hence, and unfortunately, electrographic procedures are not particularly applicable in these cases, unless of course, large enough fragments are available.

(2) It is of great assistance if one is able to differentiate between grains that are radioactive and those that are not, or at least to know that specific fragments do not affect a photographic emulsion after a reasonable period, say twenty-four hours, has elapsed. For this purpose particles to be tested are partially embedded in the softened emulsion of nuclear track plates, Kodak's types NTA or NTB have been used, the plates set aside for twenty-four hours, and finally developed, fixed and washed. If some care is taken in the latter process, the fragments will be retained in the places into which they were originally set, so that the plate with fragments attached may be studied beneath binocular or polarizing microscope. Following this, any particular fragment may be removed from the emulsion if additional determinations are to be made with it.

(3) In the fluoride-flux method, if mineral grains are placed on the surface of a thin cake prepared first by fusing K_2CO_3, Na_2CO_3 and NaF together on a platinum or nickel crucible lid (Bowie, 1949) and allowed to solidify, momentary remelting of this cake will allow incipient reaction between fusion-mixture and mineral grains. If the latter are uraniferous then the reaction zones will contain the uranyl ion and will fluoresce with a bright yellow color in ultraviolet light of either short or long wavelength. Mineral particles that were shown by chemical analysis to contain approximately 0.10 percent of UO_2 produced reaction zones that fluoresced brilliantly. It should be noted that this test may be used for detection of columbium in minerals devoid of uranium (Mackay, 1951A, 1951B) but with much care and some reservation when uranium is also present.*

Magnetite and Ilmenite. With few exceptions, for instance, the sands from near or at the mouths of Año Nuevo Creek and Pajaro River, ilmenite is more abundant than magnetite, and in many cases this predominance is a very striking one (e.g. Gazos and Whitehouse Creeks). In addition both minerals show marked granular variation (van Andel, 1950, p. 9) since, in most instances, magnetite and ilmenite with grain diameters ranging from 62-250 microns are more abundant than any other grain size. Both oxides usually form moderately abraded equidimensional particles with euhedral and subhedral fragments much less common. Only rarely has it been possible to identify any of the forms preserved on subhedra or partially rounded grains of ilmenite, whereas the octahedral form of magnetite is often evident. A slight iridescence or polychromatic film is somewhat more distinctly and more often developed on ilmenite than it is on magnetite, and this observation is not strictly comparable with that made earlier by the present writer (Hutton, 1950, p. 672) for placer material, beach and river sands. Magnetite is jet black in color and in common with members of the spinel group exhibits a shining luster and distinct conchoidal fractures, the concavities and convexities of which tend to be small. These properties are in contrast to those exhibited by anhedral ilmenite which has a less decided luster to the black color. Magnetite only occasionally exhibits films of brown or reddish-brown iron hydroxides, and this might be expected in a situation where the grains are in a state of constant motion (compare magnetite in placer material or older river gravels, Hutton, 1950, p. 672).

Quantitative analyses of ilmenite and magnetite have not been made but the following chemical data have been determined for a few examples.

(1) Ferromagnetic magnetite which appears to be homogeneous often contains appreciable Ti^{4+}; this is presumed to be titanomagnetite.

(2) Black octahedra, or fragments thereof, may show a distinct range of magnetic susceptibility, and if these crystals are isolated, crushed in oils, and viewed in transmitted light, the red translucency and anisotropic character thereof suggests that the material is martite or martitized magnetite.

(3) Some ilmenites have been observed to produce distinct fluorescent haloes in short wave ultraviolet light when tested with Bowie's flux, and are apparently uranium-bearing. By comparison with the effects produced in minerals of known uranium-content, the ilmenites tested almost certainly contain less than 0.5 percent of UO_2. The presence of uranium in ilmenite raises the question of relationship with davidite (Mawson, 1916, 1944) and a comparable mineral from Mozambique (Bannister and Horn, 1950), both of which contain much higher percentages of uranium, and are in a metamict state. When it is possible to concentrate a few milligrams for analysis and X-ray diffraction, this question will be considered further.

Chromian Spinel. Members of the chromite series of light to deep brown color are generally present in all size fractions. In a number of instances they appear to make up the bulk of opaque and semi-opaque minerals, but opacity of larger fragments and particles hinders accurate determination of frequency. If, however, magnetite and other ferro-magnetic material are removed first, the ilmenite-chromite fraction can be concentrated in a separate fraction when the Frantz separator is set at a slope of 10° and a tilt of 5°, and a current of 0.25-0.30 amps. is used; the current will, of course, depend to some extent on the composition of the spinel. If the material attracted under these circumstances is viewed with a binocular microscope and oblique illumination chromite, even if well rounded, may be readily distinguished from ilmenite on account of the characteristic jet black color, smooth conchoidal fractures, and brilliant shining luster. Nevertheless care must be observed in grain-counting since some compositions of martitized magnetite with similar susceptibilities to those of some chromites, may be present in the same magnetic fraction.

On the basis of refractive index determinations alone, the composition of members of the chromite series exhibit a distinct, yet rather narrow range, and for most examples 1.970-1.985 was found to be general (e.g. material from sands at Bolsa Point). Chromian spinel from the mouth of Gazos Creek is, however, attracted by a much weaker field than is chromite from other samples studied, and a darker brown color is evident. Refractive indices are decidedly higher, and a range of 2.02-2.04 includes most of the members of the series in Gazos Creek material; a few grains are in excess of 2.04 and a somewhat larger number range down to 1.975.

* In this connection, see particularly comment by Horne in Mackay, 1951B, viz. pp. 250-252.

Pyrite. Pyrite may be recognized in a number of sands as buck-shot-sized spherules, cubes, dodecahedra, and subhedral to anhedral fragments. However, visual recognition is only positive when some indication of form is present or remains undestroyed in subhedral fragments. If grains are anhedral or abraded, their identification may be difficult or uncertain. Color changes resulting from oxidation may lead to misidentification, or minerals such as chalcopyrite, marcasite, or arsenopyrite may be overlooked. However, none of these minerals were recognized with certainty, and even if they were misidentified, they would be fewer than 1 grain in 300.

When a new screen is employed an appreciable quantity of brass in thin flakes is removed initially from the surfaces of the cloth and holders by abrasion; it accumulates chiefly in the pan along with the finest mineral fraction. At first glance this waste has the appearance of thin fragments of pyrite but may be easily identified by the relatively smooth, wavy surfaces of the metal particles, their flexibility, and ready solubility in dilute HNO_3.

Galena. Galena, in sand from Bolsa Point,* constitutes approximately 82 percent of the —250 fraction. This is, however, a very small percentage of the total unfractionated sample since particles with diameters less than 62 microns make up only 0.03 percent of the sand. The mineral occurs in a variety of shapes whose form has been determined principally by perfect cubic cleavage. In oblique illumination a bright grey color is evident for most fragments with a thin white film or surface, possibly cerussite, noticeable here and there. It is not attracted by strong magnetic fields, and accordingly is found in the rejected fraction along with zircon, apatite, rutile, brookite, etc.

Euxenite-Polycrase Series. In blacksand paystreaks at the mouth of Año Nuevo Creek very rare fragments of a member of the euxenite-polycrase series were detected in the form of nearly opaque, deep brown grains of marked luster and striking conchoidal fracture. Thin splinters are brown in color, quite isotropic and, therefore, metamict. Refractive index is slightly in excess of 2.05. Following heating at 650°C. in air for one hour, a distinct rise in refractive index was evident and, although good X-ray diffraction powder patterns were then obtained with single fragments, anisotropy was not evident optically. Positive tests for tantalum and niobium resulted from the tannin method (Schoeller, 1937, p. 89), since, following prior removal of titanium by tartaric hydrolysis, a tannin complex of orange-red color was formed.

The positions and intensities of the lines in the X-ray powder pattern of the heated material, correspond almost exactly with those determined by Arnott (1950, p. 396) for undonbted euxenite from Nipissing, Canada, although there are some additional lines in the Año Nuevo Creek material. However, these slight divergences could be due to an inadequate ignition temperature, and in addition, might be expected in view of the variability of cell dimensions of euxenites as reported by Arnott. In this instance, heating to somewhat lower temperatures did not yield a product that gave pyrochlore or uraninite-type patterns.

The powder pattern of Año Nuevo euxenite is compared with that of euxenite from Mattawan Township, Nipissing District, Ontario, in table 8.

Table 8. Powder patterns of euxenite.

Camera diameter: 114.59 mm.
Radiation: Ni-filtered copper ($\lambda = 1.5418$ Å).

A		B		
I	*d* meas.	I	*d* meas.	hkl
4d	11.6	--	--	--
5d	9.9	--	--	--
--	--	1	7.30	(020)
2d	6.13	--	--	--
?	5.85	--	--	--
--	--	2	5.16	(110)
4	3.62	3	3.66	(130), (111), (040)
1	3.32	2	3.36	(121)
10	2.96	10	2.98	(131)
3	2.93	--	--	--
4	2.76	2	2.77	(200)
5	2.61	¼	2.61	(141)
4	2.57	2	2.58	(002), (220), (150)
--	--	½	2.54	(012)
4B	2.42	3	2.43	(022), (201), (060)
	2.40	--	--	--
3—	2.30	1	2.30	(112), (221), (151)
--	--	¼	2.252	(032), (122)
3	2.193	1	2.199	(240)
2	2.178	1	2.182	(231)
4	2.106	2	2.106	(132)
--	--	¼	2.071	(161)
?	?	½	2.025	(241)
1	1.961	½	1.970	(142)
1	1.926	1	1.935	(170), (052)
5	1.886	2	1.889	(202)
6	1.817	4	1.823	(222), (310), (152)
				(260), (171), (080)
5	1.792	--	--	--
6	1.759	3	1.769	(062)
6	1.720	4	1.723	(311), (330), (261)
--	--	½	1.679	(242)
4	1.622	3	1.635	(181), (113), (331)
		followed by many additional lines, none of which exceed a scale of 4 in Arnott's scheme.		

A. Euxenite from the mouth of Año Nuevo Creek, San Mateo Co., California. I am indebted to Professor Adolf Pabst of the University of California for his kindness in providing these X-ray diffraction data for me.
B. Euxenite, Mattawan twp., Nipissing District, Ontario, Canada (Arnott, 1950, pp. 396-7, table 5).
d = diffuse line.
B = broad line.

Pumpellyite

In addition to occurrence in composite fragments, individual rounded particles of aggregates of fine prismatic crystals of pumpellyite are found, and for individual crystals therein, the following data were determined in one instance (Año Nuevo Creek):

β = 1.685-1.690
Elongation = Y.
2V = 70° (+)
Dispersion = strong with r<v

Pleochroism: strong with

X = Z = pale yellow to colorless
Y = green with a bluish tinge in some instances.

In sands at the mouth of Gazos Creek, however, pumpellyite with brown tints and uniaxial character was found.

* In this instance, the relative abundance of galena suggests that its presence may be adventitious. Accordingly, in view of this probability, it was not listed in table 1.

In oblique illumination pumpellyite is usually bright green, distinctly brighter in color than the associated augite.

Pyroxenes

Orthorhombic pyroxenes and clinopyroxenes rank as the more important mineral groups in most of the sands investigated, and no sample or size-fraction of any sample is devoid of at least one variety of pyroxene. Clinopyroxenes predominate over rhombic types except rarely (—60 + 115 fractions of some Princeton sands), and in approximately 70 percent of individual size fractions pyroxenes are more plentiful than amphiboles. Notable exceptions are found in sands from the southernmost beaches. Amphiboles predominate more frequently in finer size fractions, possibly because of the ease with which slender prismatic or needle-like cleavage fragments are developed from larger grains of amphibole by abrasion, and these pass more readily through finer screens than the equidimensional pyroxene cleavage particles.

Augite. Augite ranks as one of the more important constituents of the sands; some variety of monoclinic pyroxene has been found in every sample and in almost every grade size of these samples. In general, clinopyroxenes constitute the greater percentages of the mineral assemblages of larger grade-size, but notable exceptions are sands from near the mouth of Butano Creek, where clinopyroxenes make up more than half of the finest grade-size fraction.

In most finer fractions augite is anhedral, often showing pronounced conchoidal fractures (fig. 4, no. 20), although grain shapes determined by prismatic cleavages are common. In addition, such forms are associated in these size fractions with subhedral and less often euhedral crystals of simple habit with *s* {111}, *a* {100}, *m* {110}, and *b* {010} as dominant faces (fig. 4, nos. 21, 23). In larger particle-sizes, irregularly shaped anhedral fragments are still common, but a considerable degree of rounding is more often evident.

Results of selective solution may be most pronounced; outstanding examples were seen in material from the beach at Aptos. There were remnants of pyroxene grains with multiple terminating pyramids in all stages of development, the so-called "cockscomb" or "hicksaw" structures so well described and figured by Ross et al. (1929, pp. 184-5; plates 23B, C; 24), Edelman and Doeglas (1932), and others. The etching or solution does not appear to have preferred clinopyroxenes of any specific composition nor has it been restricted to fragments of any particular grain-size. On the other hand, excessively attenuated needle-like fringes appear to be more or less confined to rhombic pyroxenes (fig. 4, nos. 15, 17) of finer particle sizes.

Clinopyroxenes belong to two varieties, a pale green diopsidic type and a purple or brownish titaniferous augite with very weak to moderate absorption. Any genetic relationship between these two varieties was recognized rarely, as for example, the occasional fragments of green diopsidic augite rimmed by titan-augite in —32 +60 mesh material from the mouth of Tunitas Creek. In finest size fractions it is usually difficult to detect any color at all, though color is easily seen in coarser fragments. Consequently it should be understood that the figures for green augite in —250 fractions and to some extent those for —115 +250 fractions as well are indicative of clinopyroxenes without reference to color.

Diopsidic augite shows a range from colorless to pale green with faint pleochroism sometimes evident. Several determinations of optical properties showed a general range as follows:

$$\alpha = 1.690 \pm 0.004$$
$$\gamma = 1.715 \pm 0.004$$
$$\gamma - \alpha = 0.025$$
$$Z \wedge c = 42\text{–}44°$$
$$2V = 58\text{–}62° \ (+)$$

In one case 1.681 was recorded for the X vibration direction, and in another 1.721 for Z.

Pleochroism is absent in most grains of titan-augite and is only detectable when purple to brownish tints are moderately strong. Optical properties generally did not differ significantly from those recorded for colorless to pale green diopsidic clinopyroxene, although occasional fragments from Moss Landing gave: $\alpha = 1.705\text{-}1.712$, and $\gamma = 1.732\text{-}1.738$. On the other hand, in Aptos material $\alpha = 1.686$ and $\gamma = 1.713$ were recorded for a purple augite.

Although diopsidic augite is usually free from inclusions the following have been recognized: plagioclase (andesine to labradorite), apatite, particles of brown glass and opaque iron oxides. When separated from the host, the opaque inclusions from a single grain often show distinct ranges of magnetic susceptibility and a wide range is found in inclusions from grain to grain. Susceptibility and chemical reactions suggest that the opaque inclusion material may range from magnetite through titanomagnetite to ilmenite in composition. Similar inclusions were recognized in purple-colored titan-augite and, in addition, inclusions of very delicate vermicular-like form arranged either irregularly or en echelon fashion are common. In a few instances the frequency of iron oxide inclusions in individual detrital grains, and the proportions of such inclusion-bearing grains in some sands, are so high that independent iron oxide fragments cannot be conveniently fractionated magnetically from the ferromagnesian constituents; the inclusion-charged ferromagnesian minerals were found to be as susceptible as many of the iron oxide grains. This is especially so for sands in the Aptos area where pyroxenes and amphiboles may predominate over ilmenite for each size fraction separated at 0.15 amps. The ferromagnetic fractions exhibit similar characteristics in this case.

Hypersthene. Hypersthene is ubiquitous except in the finest fraction of sands from the mouth of Tunitas Creek, and in samples from the southern part of Monterey Bay. Orthopyroxene is usually subordinate to clinopyroxenes in each size fraction but unlike the latter, the frequency of the orthorhombic variety is generally at a maximum between 0.125 –0.25 mm.

The pyroxene occurs in grains that range from highly irregular anhedral forms with strong conchoidal fracture surfaces predominant in the finest grade sizes, through subhedral or well rounded prismatic forms, (fig. 4, no. 1) chiefly in coarser fractions, to distinctly euhedral crystals that do not exhibit abrasion effects (fig. 4,

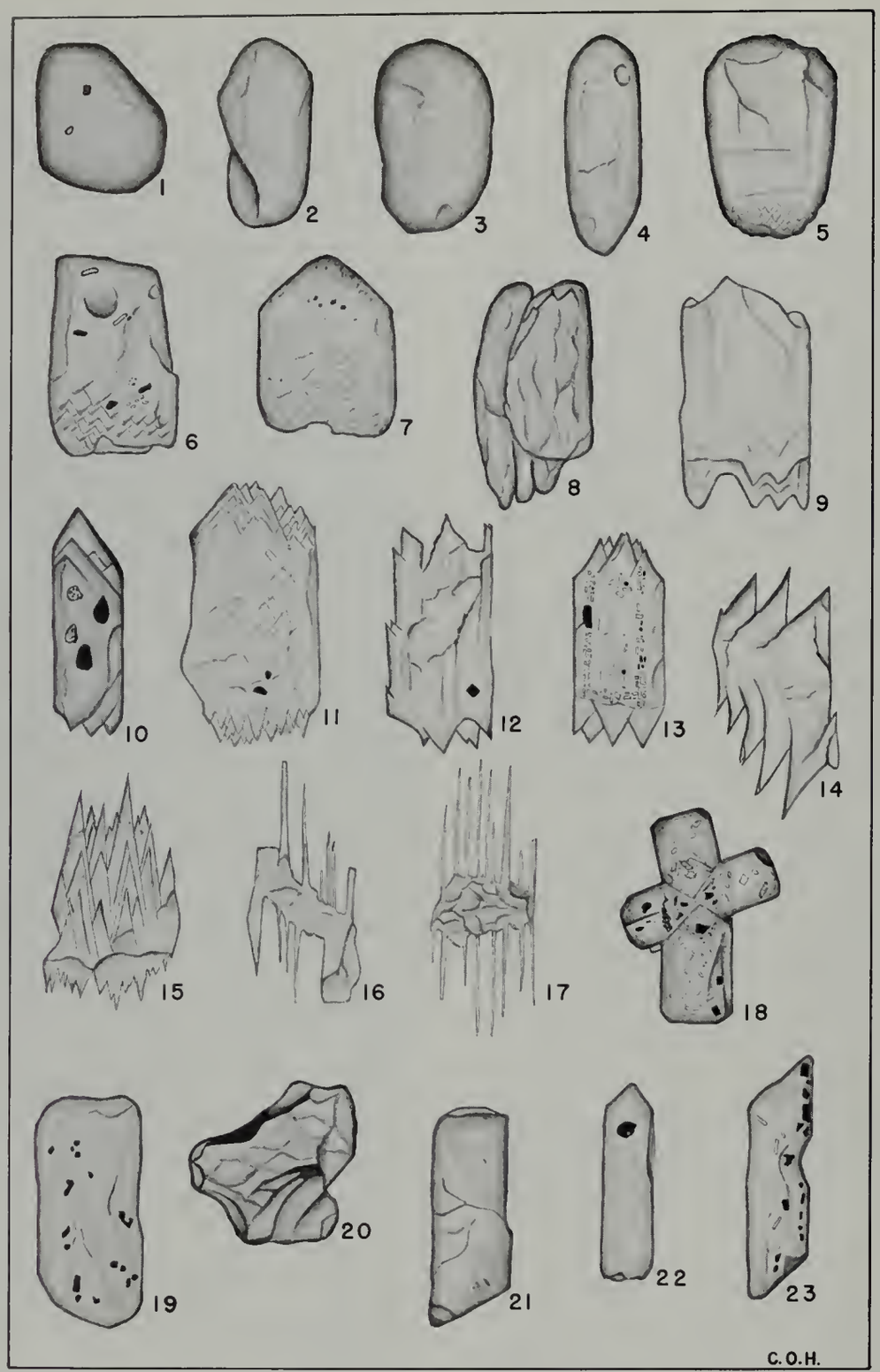

FIGURE 4. Typical crystals and fragments of pyroxenes. (1) Inclusion-free, very clear hypersthene with cleavage clearly visible; well rounded. Oriented perpendicular to X. —60 +115 fraction of blacksand, mouth of Tunitas Creek, San Mateo County. X 130. (2) Rounded green augite. —60 + 115 fraction of sand from small bay 20 chains west of mouth of Whitehouse Creek, San Mateo County. X 71. (3) Well-rounded, clear, diopsidic augite; twin lamellae evident. Same locality as no. 2. X 71. (4) Hypersthene. —115 +250 fraction of beachsand. Aptos. X 125. (5) Rounded green augite with incipient etching. Same locality and magnification as no. 4. (6) Hypersthene. Same locality and magnification as no. 4. (7) Same as no. 4. In magnetic fraction separated at —0.10 + 0.35 amps. (8) Same as no. 7. (9) Same as no. 7. (10) Hypersthene with clear remnants at crystal extremities that have the appearance of outgrowths. Fraction, locality, and magnification as for no. 7. (11) Pale green augite. —25 fraction of beachsand from a point north of the mouth of San Gregorio Creek, San Mateo County. X 190. (12) Same as no. 11. (13) Hypersthene. —115 +250 fraction of Aptos beachsand (magnetic fraction —0.10 +0.35 amps). X 125. (14) Same as no. 11. (15) Hypersthene. Fraction, locality, and magnification as for no. 11. (16) Same as no. 11. (17) Same as no. 15. (18) Glomeroporphyritic aggregate of hypersthene crystals. —32 +60 fraction of Aptos beachsand. X 54. (19) Same as no. 11. (20) Titan-augite, much chipped. Fraction, locality, and magnification as for no. 2. (21) Green augite oriented parallel to (010). Fraction, locality, and magnification as for no. 13. (22) Clear, slender hypersthene crystal in heavy residue from Purisima formation. North of mouth of San Gregorio Creek, San Mateo County. X 180. (23) Same as no. 21.

nos. 10, 22); the euhedral ones are perhaps more usual in finer size fractions but are also found among the coarser sizes. Occasional undamaged glomeroporphyritic aggregates have been found (fig. 4, no. 18) in which the individuals show no simple crystallographic relationship to one another; twinning is thus discounted.

As with augite, hypersthene exhibits every degree of completeness of solution effects from incipient development of multiple pyramidal terminations (fig. 4, nos. 6-9) to minute fragments with very slender, needle-like attenuations that are often two or three times as long as the central remnants (fig. 4, nos. 15, 17). It should be noted at this point that fragments with the most pronounced solution effects, that is, remnants with the longest and most delicate pyramidal terminations, are more or less restricted in their distribution to the finest grade size; in other words, to grains with diameters not in excess of 62 microns. Larger pyroxene fragments (125-250 microns) exhibiting solution effects show some degree of blunting of the multipyramidal terminations, and extremely attentuated needle-like fringes are apparently unable to develop or to be maintained in such instances (fig. 4, nos. 8-9). This would appear to be a fine example of the incompetence of abrasion processes, even on open beaches exposed to storm conditions of some violence, when minute particles are cushioned by water films.

In the samples investigated the minute fragments with attenuated fringes did not appear to be limited to any particular zone of a beach and do not seem to be any more numerous at storm level than at low water mark.

The finest sized particles of hypersthene are colorless or nearly so, but coarser material is moderately pleochroic according to the usual scheme. Distinct differences in absorption between the three vibration directions are difficult to detect but where absorption is most pronounced the scheme $X > Z \geqslant Y$ would seem to apply. In some preparations hypersthene fragments were found to be oriented in the mounting medium with the basal plane parallel to the plane of the microscope stage, and at first sight the pleochroism, brown (X) to golden yellow (Y), suggested that of staurolite. However, such grains were perpendicular to the biseetrix Z and have other properties characteristic of hypersthene.

Except for specimens from occurrences near Pajaro River, refractive indices fell within the following range in the majority of samples:

$$\alpha = 1.685 - 1.688$$
$$\gamma = 1.698 - 1.700$$
$$\gamma - \alpha = 0.012 - 0.013$$

Zoning may be quite marked and is made more apparent by distinctly stronger absorption in narrow peripheral zones that are not necessarily abruptly demarcated from the central areas.

In material collected just above high water level, three-quarters of a mile south of the mouth of Pajaro River, the following values were obtained:

$$\alpha = \quad -, 1.694, 1.696, 1.696$$
$$\gamma = 1.699, 1.708, 1.710, 1.710$$

Taken together, the refractive indices indicate a compositional range of 33-42 percent of the orthoferrosilite molecule (Henry, 1935, p. 223, fig. 1).

Very few hypersthene fragments are completely devoid of inclusions, and the following are common:

(1) Rounded or irregularly shaped grains of magnetite, titanomagnetite and ilmenite; on account of the abundance of these contaminants in some cases, pyroxene crystals may be ferromagnetic or so strongly paramagnetic that they are concentrated with ilmenite when the sands are magnetically fractionated.

(2) Unidentified disoriented, colorless grains of low refractive index.

(3) Irregularly shaped and spaced gas cavities; occasionally these may be grouped into dense aggregates.

(4) Prismatic crystals of apatite.

(5) Glass.

(6) Euhedral zircon.

(7) Most, or combinations, of the minerals or phases just listed may be found aggregated into distinct zones that exhibit marked parallelism to orthopyroxene crystal boundaries.

Rutile

Rutile, a constant minor constituent, does not exceed 1 percent of any fraction of any of the sands studied. Worn and broken prismatic crystals with rare geniculate twins are characteristic and these exhibit either (a) golden yellow to red-brown dichroism with intense absorption parallel to the *c* axis in a few cases, or (b) golden yellow to yellowish-brown for the ordinary and extraordinary rays respectively, with little difference in absorption in the two directions. In the — 60 + 115 size fraction, Whitehouse Creek material contains fragments that are very deep red in color and almost opaque for any orientation. A score of fragments were hand-picked and after fusion in potassium pyrosulfate and solution positive tests for tantalum were obtained; the presence of niobium was not verified.

In oblique illumination rutile may be readily identified and differentiated from oxyhornblende, cassiterite and other dark brown prismatic minerals by its adamantine luster; the presence of striations is an assistance.

When color is intense rutile fragments are nearly black in oblique lighting but are, however, rarely devoid of a dark brown resinous glint; the latter is particularly evident where conchoidal fractures have partially developed without actual separation of splinters.

Sphene

Sphene is ubiquitous and, in general, crystals and fragments that have diameters ranging from 125-250 microns are noticeably the more abundant. Habit varies considerably from grain to grain but the range of forms does not change appreciably from sample to sample. Every gradation is to be found from sharply euhedral "envelope"-shaped crystals with dome {102}, basal plane {001}, and orthopinacoid {100} prominently developed, to fragments of euhedra, or on the other hand, well rounded particles that may exhibit chatter marks. In crystals from the south side of the mouth of Tunitas Creek, deep rhomboidally shaped pits were seen, and at the same time pronounced zoning was made evident solely by patchy distribution of anomalous interference tints in orientations with Bxa perpendicular, or nearly so, to the microscope stage.

Two varities of sphene have been noted and both of these are usually present in the same sample. The first of these forms pale yellow, well worn grains with a dusty appearance that may be due to numerous unidentified translucent, pale yellow to colorless inclusions. Numerous cracks are present that do not seem to originate

at any specific point or inclusion. Due to the degree of rounding, preferred orientation of crystals in mounting media is not very noticeable. Dispersion is distinct and pleochroism faint yet clear, with X′ = pale yellow to nearly colorless and Z′ = deep salmon pink (rarely red-brown; Whitehouse Creek), in some instances, but with X′ = pale golden yellow and Z′ = golden yellow dominant. Pleochroism may be much more satisfactorily observed when crystals, or fragments thereof, are immersed in a liquid of refractive index about 1.95, since, in mounting media of very dissimilar refractive index, appropriately oriented crystals exhibit marked change of brightness on rotation of the microscope stage due to high birefringence; this effect of alternate brightening (X′ parallel to plane of polarized light) and darkening (Z′ parallel to plane of polarized light) is suggestive of pleochroism.

The second variety of sphene is also pale yellow, although in some instances nearly colorless, and crystals and fragments are generally free from inclusions. Rounding is less noticeable and angular, or often euhedral forms with {102} prominent, are more common. Preferred orientation of grains in mounting media is much more obvious than is the case with the first variety, interference figures are clearer, dispersive effects are more striking both in interference figures and between crossed nicols, and the optic axial angle is greater. Cracks are not so evident.

No significant differences in the α refractive indices have been detected so far, and values that range from 1.887 to 1.898 have been found for the two varieties. Additional work in this connection is necessary.

Tantalite

Identification of rare, dark red, irregular fragments in material from the mouth of Año Nuevo Creek as tantalite is somewhat doubtful, but the data determined are recorded for the sake of completeness and to point out that distinction between tantalite and deeply colored tantalian cassiterite, on the basis of some optical properties alone, may not be entirely satisfactory unless complete information can be obtained. The refractive index for X′ is in excess of 2.06 (distinction from cassiterite) but birefringence does not appear noticeably different from that for cassiterite. Fragments are unaffected by hot concentrated HCl, give a negative test for Sn^{4+} with zinc and HCl, and curiously, if tantalite is a correct diagnosis, contain negligible Mn^{2+}; with tannin, orange colored complexes of Ta^{5+} and/or Nb^{5+} compounds were obtained. Cleavage is not apparent, nor could satisfactory interference figures be secured.

Uranoan Thorite

Uranium-bearing thorite, a constituent of many sands collected at points between Princeton and Monterey Bay, is largely restricted in size to diameters less than 125 microns.

Habit and Color. Most thorite forms exceptionally well abraded particles, occasionally spherical, with traces of conchoidally shaped fracture surfaces that are very nearly obliterated by the natural polishing processes to which the mineral has been subjected. There is every gradation between such forms and less common stumpy, prism-like, grains from which all traces of crystal faces have been removed, and, in the other extreme, highly angular fragments with strikingly well developed conchoidal fractures. No grains were found with definitely identifiable crystal faces.

A rather wide range of color is found and an opalescent pale green, close to Ridgway's Light Grape Green (25‴ YG-Y, b) is possibly the dominant one. A shade of brown is less often evident whereas some crystal fragments trend towards Ridgway's Corydalis Green (29‴ GG-Y, d). A color close to Courge Green (25 YC-Y, i) is found for a few grains with Orange-Citrine (19 YO-Y, k) unusual. Almost colorless particles are rare. The color of a pure sample of uranoan thorite particles with diameters 62-125 microns is comparable to Ridgway's Yew Green (27″ G-Y, m) when viewed en masse in ordinary light.

The prime cause of the wide range of colors found in Año Nuevo Creek thorite is obscure. The green opalescent color that is most commonly seen may result from the presence of U^{4+} ions, and perhaps much paler yellowish green tints might arise when U^{6+} ions are dominant instead. On the other hand, the range of colors displayed by this mineral is rather strikingly similar to that found in common silicate glasses with comparable or less amounts of iron to that found in this mineral (table 9), that have been prepared under a variety of oxidizing and/or reducing conditions. The range of color that may be developed in such cases is clearly due to the small percentage of iron present, but little appears to be known of the relationship between the valence of iron and the color of the corresponding glass. Certainly, it is not merely a question of divalent iron producing a green glass, and a brown glass resulting from oxidation of iron to the trivalent state, since in some instances, green glasses have resulted with iron in the higher state of oxidation; even blue colors have developed in glasses when approximately equal amounts of Fe^{2+} and Fe^{3+} are present. That thorite, described here, is in a glassy, metamict condition, does not make the comparison with artificial silicate glasses any more valid, since a wide range of color from green to brown may be observed in non-metamict thorite.

Thus little specific data are available to assist in resolving this question of color, but it is tentatively suggested that the range of color in thorite may be due to the iron present, rather than to the uranium content. The range of magnetic susceptibility found for this mineral may support this conclusion.

In oblique illumination uranoan thorite is readily differentiated from other pale green or brownish green grains, such as many composite fragments of saussuritic composition, grossular, members of the clinozoisite-epidote series, vesuvianite, etc., first, by striking opalescent or chatoyant appearance, and second, by remarkably smooth and polished surfaces of the rounded particles. Here and there, for example at the mouth of Gazos Creek, thorite may exhibit curious breadcrust-like surfaces that are particularly evident in brown-colored varieties but not restricted thereto.

In shortwave ultraviolet light (2540 Å.) a very faint deep blue fluorescence was detected for some particles, but when these were segregated by hand-picking and examined in liquid media by transmitted light, nothing distinctive was detected. On the other hand, a blue

fluorescence of brighter hue was noticed for patches of alteration (?) material associated with some thorite, and, here and there, bright yellow-green fluorescent spots suggest the presence of uranyl compounds as other alteration products. No effects were noted when ultraviolet light of longer wavelength (about 3600Å) was employed as the source of oblique illumination.

The ability of uranoan thorite described herein to produce faint fluorescence in shortwave ultraviolet light appears to be destroyed by heating to temperatures in excess of 680°C.

Inclusions. Inclusions are uncommon, and especially so for highly translucent clear green varieties; on the other hand, alteration products appear to be slightly more frequent in brownish grains than in green. Some of the inclusions and heterogeneities observed may be summed up as follows:

(1) Brown areas that appear due to clouds of "limonitic" dust-like particles in grains that otherwise exhibit blotchy areas of weak birefringence.

(2) Zonary arrangement in which relatively wide brown central areas of dusty aspect are sharply demarcated from clear, green peripheral zones.

(3) Yellow to orange colored blotches, often anisotropic, in otherwise homogeneous, inclusion-free crystals of pale green color. The yellow or orange material is soluble in warm dilute HNO_3, and since this solution fluoresces in shortwave ultraviolet light, the presence of the uranyl radical in these distinctively colored areas is suspected.

(4) Aggregates of unidentified dust-like particles from which systems of cracks may radiate outward.

(5) Semi-opaque isotropic areas of much lower refractive index than the thorite.

(6) Sharply demarcated, unsymmetrical narrow zones of color banding. (fig. 5, no. 9.)

(7) Cavities filled with gas or liquid; rarely bubbles (fig 5, no. 19).

(8) Systems of anastomosing cracks, usually thread-like, that do not seem to be associated with inclusions of any kind.

(9) Deep brown opaque inclusions; usually as rounded grains or blebs.

When free from inclusions or from what seem to be alteration products, uranoan thorite is generally isotropic, though a few grains have a faint glimmer of birefringence. A spherulitic structure on a cryptocrystalline scale is suggested for the birefringent grains on account of the appearance of minute black crosses when such material is viewed between crossed nicols; the arms of the crosses are parallel to the ocular cross hairs and the direction parallel to the elongation of the "fibers" is fast.

Chemical Properties. Uranoan thorite is exceedingly refractory and even when reduced to excessively fine powder, hot concentrated acids have little effect thereon, and gelatinization was not evident. However, if fragments of thorite are boiled in a strong solution of oxalic acid for about 2 minutes, washed, and then dried, white films of thorium oxalate are developed; this behavior facilitates recognition of thorite when other green, isotropic, but non-thorium-bearing minerals are present. A sample was prepared by careful electromagnetic fractionation, after preliminary concentration by screening and flotation, and brought to a state of high purity by careful hand-picking in oblique illumination with white light and finally with shortwave ultraviolet light. The latter precaution was necessary in order to guarantee absence of both zircon and scheelite; neither ZrO_2 nor WO_3 were detected by analysis.

The composition of thorite from Año Nuevo Creek is quite similar to that recorded by George (1951, p. 131) for thorite from concentrates obtained by the La Grange Dredging Company in the course of operations on the Tuolumne River, near La Grange, California. However, uranoan thorite from the Año Nuevo locality contains an appreciable amount of copper and the total quantity of water is released at temperatures below 105° C. The analysis of Tuolumne River thorite, on the other hand, shows moderate amounts of alumina and water, although George does not give any indication of the temperature at which water was given off; in fact, the considerable quantity of water in thorite from the Tuolumne River locality is not commented upon by George, other than to state that the high specific gravity "is probably attributable to the absence of appreciable water of hydration."

Table 9. Analyses of uranoan thorite.

	A.	B.
Rare earths	0.24	0.54
ThO_2	72.93	71.61
UO_2	6.95	8.36
FeO	0.58	0.59
Al_2O_3	0.32	1.29
TiO_2	0.04	0.10
MnO	<0.01	--
CuO	0.11	--
PbO	0.10	0.10
CaO	0.42	--
MgO	0.07	0.01
P_2O_5	trace	--
SiO_2	17.96	16.47
H_2O+	nil	0.86
H_2O-	0.22	
	99.94	100.00

A. Uranoan thorite separated from blacksands, mouth of Año Nuevo Creek, San Mateo County, California. Ta_2O_5, Nb_2O_5, ZrO_2, and WO_3 were not detected. Rare earths are chiefly Y_2O_3. Analyst: Johnson, Matthey.

B. Uranoan thorite from dredge concentrates, La Grange, California. Total includes ZrO_2 0.07 per cent (George, 1951, p. 131, column 3.). Analyst: National Bureau of Standards

When the two thorite analyses are calculated on the basis of molecular proportions the ratio of ThO_2 and other metal oxides to silica is low in each case, when it should be 1:1. For the Año Nuevo mineral ThO_2 etc.: SiO_2 is 1:0.903, whereas the corresponding ratio for thorite from Tuolumne River (George, 1951, p. 131) is 1:0.845, a discrepancy which George believed might be due to an incorrect silica determination. Although this could be the case, it should be remembered that we are unaware of the states of oxidation of both iron and uranium. Certainly in view of the low percentages of Fe^{2+} an incorrect assumption in this respect will be of little moment but with uranium it is a different matter.

Frondel (1953) has demonstrated that $[SiO_4]$ groups in thorite may be replaced by $[OH]_4$ in a manner similar to that found in hydrogrossular and other minerals. If, then, the two analyses in table 9 are recalculated on the basis of 16 oxygen atoms to the unit cell, and water is taken into consideration (table 10), much better ratios between Th etc. and (Si+H) are obtained (1:0.98 and 1.08 for Año Nuevo Creek and Tuolumne River thorite respectively). This seems to support the conclusion that the water determined to be present in these two minerals may instead, be $[OH]_4$ substituting for $[SiO_4]$, rather than water molecules, although it should be stressed that the 0.22 per cent of H_2O in Año Nuevo Creek

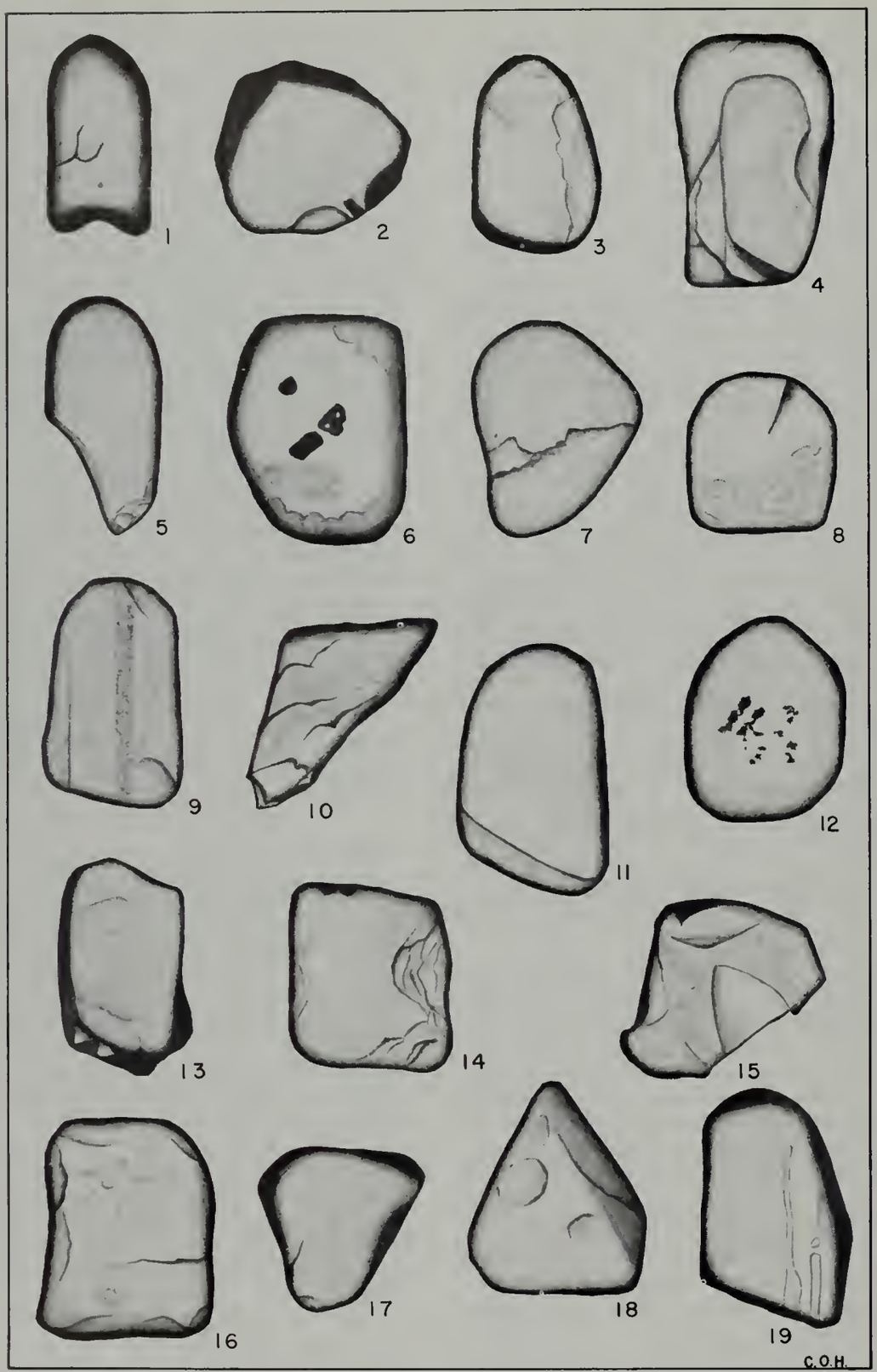

FIGURE 5. Typical habit and form of detrital uranoan thorite. Locality, beachsands at the mouth of Año Nuevo Creek. Magnification, X 200. (1) Slightly abraded, green thorite of tetragonal form. (2) and (3) Abraded and chipped, green anhedra. (4) Excessively chipped and rounded grain; color pale green. (5) and (6) Chipped, abraded grains; pale green. (7) Poorly birefringent, orange-colored thorite. (8) Isotropic orange thorite. (9) Abraded brown thorite with bands of inclusions of dust-like size, but undiagnosed. (10) Abraded chip of dirty green thorite. (11) Well-rounded clear green thorite. (12) Pale green thorite with semi-opaque inclusions; striations may be zonary structure. (13) Deep green abraded grain with lines of submicroscopic inclusions. (14) Green fragments, perhaps a basal section. (15) Deep green particle of thorite. (16) Practically colorless thorite with chatter marks. (17) and (18) Clear brown grains. (19) Clear green particle with gas cavities.

Table 10. Recalculation of thorite analyses on the basis of 16 oxygen atoms per unit-cell.

A. Año Nuevo Creek	Weight percent	Metal atoms		B. Tuolumne River, (La Grange)	Weight percent	Metal atoms	
R.E.*	0.24	.03		R.E.*	0.54	.06	
ThO_2	72.93	3.54		ThO_2	71.61	3.45	
UO_2	6.95	.33		UO_2	8.36	.39	
FeO	0.58	.10		FeO	0.59	.10	
Al_2O_3	0.32	.08	4.20	Al_2O_3	1.29	.32	4.33
TiO_2	0.04	--		TiO_2	0.10	.01	
CuO	0.11	.01		CuO	--	--	
CaO	0.42	.09		CaO	--	--	
MgO	0.07	.02		MgO	0.01	--	
SiO_2	17.96	3.84	4.15	SiO_2	16.47	3.49	4.70
H_2O	0.22	.31		H_2O	0.86	1.21	

Formulae:

A. $[Th_{3.54}\ U_{0.33}\ Y_{0.03}\ Fe_{0.10}\ Al_{0.08}\ Cu_{0.01}\ Ca_{0.09}\ Mg_{0.02}][SiO_4]_{3.84}[(OH)_4]_{0.31}$

B. $[Th_{3.45}\ U_{0.39}\ Y_{0.06}\ Fe_{0.10}\ Al_{0.32}\ Ti_{0.01}][SiO_4]_{3.49}[(OH)_4]_{1.21}$

* R.E. refers to rare earths and in both instances these have been taken to be yttrium.

thorite was given off below 105° C. The ratio of 1:1.08 in Tuolumne River thorite is, of course, too high, and some water molecules may be present as well in this case.

Although the work of Frondel has shown that alteration of primary thorite to hydrothorite gives rise to a product that is fully crystalline, and not metamict, the minerals described here are metamict.

Physical Properties. The mineral is either isotropic, or at the most, it may exhibit feeble birefringence; accordingly, it is in a metamict condition. In no instance, however, were values comparable to those recorded by George (1951) for La Grange, Tuolumne River thorite observed, nor has the present writer ever found birefringences of the order noted by George in his own concentrates of Tuolumne River thorite. A range of refractive indices has been determined for the analyzed material, and 1.850±0.002 appears to be inclusive. For impure thorite concentrates, a range of 1.841–1.859 was found, but with the greater proportion of the material lying within the range 1.849–1.854. Both refractive indices and color undergo marked transformations when Año Nuevo thorite is heated in air, and the data in table 11 are indicative of these changes.

Since heavy media could not be profitably employed for specific gravity determinations, a micropycnometric method was used; this entailed use of several milligram amounts of thorite grains, rather than individual particles, and the values obtained in this manner for several pure fractions that exhibited slightly differing magnetic susceptibility were 6.27±0.03 at 26° C.

Employing a camera of 57.3 mm. diameter, and nickel-filtered copper-radiation, a faint, but well-defined powder pattern was obtained from a single crystal of uranoan thorite, 0.125 mm. in length, after it had been heated in air for 4 hours * at a temperature of 860° C. The lines on this pattern are those yielded by the face-centered cubic lattice of thorianite (table 12). After demounting the crystal, it was heated again, but this time to a temperature of 1250° C. for an additional four-hour * period, and the X-ray diffraction pattern now

* It was determined in subsequent experiments that much shorter periods of heat-treatment would cause satisfactory recrystallization of metamict thorite.

Table 11. Effect of heating on physical properties of Año Nuevo thorite.

Temperature in degrees Centigrade	Refractive indices: Major portion	Refractive indices: Range	Color in transmitted light
Normal	1.850	1.841-1.859	Pale green
680° for 2½ hours	1.865	1.858-1.869	Golden brown
800° for 3¼ hours	1.838	1.829-1.842	Golden brown
860° for 4 hours	1.805	1.799-1.808	Deep brown
1100° for 4 hours	1.788	1.779-1.791	Very dark brown. (dark coffee brown in oblique illumination).

Table 12. Powder pattern of uranoan thorite after being heated to 860° C. for four hours. Locality: Mouth of Año Nuevo Creek, San Mateo County, California.

d_{obs}	*hkl*	*I* *
3.23	(111)	10
2.78	(200)	6
1.96	(220)	7
1.69	(311)	8
1.62	(222)	2
1.40	(400)	2
1.29	(331)	4
1.26	(420)	3
1.15	(422)	3
1.08	(511), (333)	3
0.99	(440)	v. faint
0.95	(531)	2
0.94	(600), (442)	2
0.885	(620)	1

* Intensities were determined visually.

obtained from the crystal corresponds to that of the monoclinic dimorph of $ThSiO_4$—huttonite.

Age of Año Nuevo Creek Thorite. While fully cognizant of the uncertainties attached to age determinations of material that has not been found in place, it is interesting that the ratio U-Th/Pb for Año Nuevo Creek thorite leads to an age of 25.25 x 10^6 years when Holmes' (1931, p. 207) logarithmic formula is employed, and that this is close to the age of 21 x 10^6 found by George (1951, p. 130) for Tuolumne River thorite of placer origin that was apparently derived from Sierra Nevada intrusives.

Although the original host of the Año Nuevo Creek thorite is not known, it would seem most probable that it has been derived from Sierra Nevada intrusives. Accordingly, an age of 25.25 x 10^6 years is quite unlikely, and in view of the well-known solubility of the thorium-lead isotope, Pb^{208}, a loss of lead may have taken place during the process of metamictization, or perhaps during the transfer to its present locality—especially if acidic ground-waters were available.

Topaz

Topaz was recognized in the finest size fractions of two samples as water-clear, but irregularly shaped cleavage fragments that exhibit centered biaxial interference figures.

Tourmaline

Tourmaline, surprisingly rare but widely distributed, usually forms abraded or fragmentary short to stumpy prismatic crystals with terminal faces that are occasionally preserved. Clouds of dust-like particles are often

present and parti-colored fragments were rarely seen. Crystal fragments with quite intense dichroism in shades of brown appear to be dominant, with blue or purplish tints much less abundant. Other dichroic schemes infrequently observed are O = red, E = colorless (Año Nuevo); O = deep green and nearly opaque, E = pale green (Bolsa Point); O = deep greenish brown, E = red-brown (Butano Creek).

Vesuvianite

Rare vesuvianite forms rounded to sub-rounded colorless to very pale green grains of faint birefringence, but material from sands at the mouth of Whitehouse Creek was rather distinctive; the following data were determined for it:

1. The mineral was concentrated electromagnetically when the separator was set with a slope of 15°, a tilt of 5°, and a current of 0.45 amps. was employed.
2. $\alpha = 1.716 \pm 0.002$
   $\gamma = 1.719$
   $\gamma - \alpha = 0.003$
3. The optic axial angle was zero in red light, but a small angle is evident in light near the short end of the visible spectrum; sign is positive.

These data are comparable to those given by Winchell (1951, p. 508) for the variety, viluite, but since insufficient material is available for any additional work further comparison is unwarranted at this time.

Xenotime

The yttrium phosphate xenotime has been definitely recognized in one heavy mineral assemblage, the —115 +250 mesh fraction of material from the mouth of Año Nuevo Creek. It was found concentrated in the electromagnetically separated monazite-rich fraction, although xenotime was found to have a greater susceptibility than that of monazite.

Xenotime forms colorless, rounded, equidimensional grains of dusty aspect due to fine pale colored inclusions which are often aggregated together to produce what at first sight has the appearance of a stain.

It is uniaxial and optically positive with $\alpha = 1.724$ and $\gamma = 1.818$. Tests with alpha-track plates suggest that the xenotime described herein is distinctly more radioactive than the associated monazite but otherwise no compositional data are available.

Zircon

Zircon is a constituent of each of the size fractions —250, —115 +250, and —60 + 115 in every sample studied. In the first size group zircon may range from 75 percent down to approximately 1 percent, but with higher values the more usual ones. Zircon exhibits very much the same range of frequency in the second size fraction, but in the —60 + 115 and coarser grade sizes zircon percentages decrease rapidly.

It is found in a wide variety of forms and, except for the more obvious division into colorless and purplish types, no simple classification appears to be possible.

Colorless Zircon. By far the greater proportion of zircon in the finest size fractions is euhedral but the degree of rounding increases strikingly with increase of grain-size and may attain considerable perfection with the development in some instances of cigar-shaped forms. Crystals less than 62 microns in diameter show little evidence of abrasion whereas the larger crystals or fragments in the —115 + 250 fraction do. Fragments bounded by conchoidal fractures are found in the finest fractions but they are increasingly less frequent in assemblages of larger grain size. In more rounded grains pits and chatter-marks are often seen by inspection in oblique illumination.

The dimensions, that is length and breadth, of euhedra show a fairly wide range but no distinct groupings seem feasible. The ratio length: breadth ranges from 1.9–4.5 with the majority of grains from all samples, 2.2–2.5.

Crystals of moderately complex habit are dominant whereas crystals with first order prisms and pyramids alone are decidedly rare. Perhaps the most common forms developed in any one crystal are *m* {110}, *a* {100}, *x* {311}, *p* {111}, and *u* {331}.

Inclusions are general, and although few grains are devoid of them, only rarely is a considerable amount of the zircon of any one sample moderately paramagnetic on account of aggregates of opaque iron oxides (— 115 + 250 fraction of material from near the mouth of Whitehouse Creek). The common forms of inclusions observed are:

(a) Unoriented needles of dark brown material (= rutile ?).
(b) Narrow thread-like channels parallel to the *c*-axis that may be gas-filled since the refractive index is extremely low.
(c) Prismatic laths of ilmenite and more or less rounded grains of magnetite.
(d) Gaseous and liquid cavities.
(e) Colorless, acicular crystals as yet unidentified.
(f) Prisms of rutile, apatite, zircon, monazite.

Occasional zircons of faint blush pink color were noticed and such crystals are probably more correctly included with the group just described than with hyacinth, since they do not exhibit any of the characteristic features seen in hyacinth. Such zircons are generally sharply euhedral and perhaps more often free from inclusions than colorless zircon; otherwise they are similar.

Hyacinth. The purple-colored variety of zircon, hyacinth, is present in most assemblages but it rarely exceeds more than a few grains in any one sample. Although restricted numbers did not permit detailed studies, the characteristic features of color, zonary structure, notable rounding, anastomosing systems of fissures or cracks are all present, and comparable in every way to those previously recorded for hyacinth (Tyler et al., 1940; Hutton, 1950).

Malacon. In material from near the mouth of Tunitas Creek, San Mateo County, rare particles were observed that are believed to be malacon, but this opinion is put forward with some uncertainty. The dusty, brown, grains have tetragonal symmetry, and a birefringence that does not exceed 0.015. Refractive index and specific gravity are approximately 1.78 and 4.1 respectively.

Doubtful Identifications

In the foregoing mineralogical descriptions attention has been drawn to the uncertainty of some data and the interpretations based thereon. Furthermore in some instances optical data determined for some minerals may not correspond with any recorded data, or correspond in a general way only with some extremely rare or unusual species so that reference to such mineral types does not seem to be warranted. In every case where there was some doubt insufficient material prevented application of adequate chemical or optical tests. However, the incomplete data are recorded in the hope that they may prove of use to other investigators.

In a fraction rejected by the electromagnet at maximum field strength occasional grains were recognized in material from the mouth of Año Nuevo Creek (— 115 + 250 mesh), with the following properties:

Color: deep blue to bluish green.
Pleochroism: faint.
N : 2.0 (*ca*).
Birefringence: 0.03 (*ca*).
Uniaxial and optically negative.

These data are comparable to those recorded for the hydrous oxychlorides boléite and pseudoboléite.

From sands near the mouth of Whitehouse Creek occasional fragments were found in a magnetic fraction rejected at 0.75 amps but attracted at 1.18 amps. (slope 15°, tilt 5°), that have not been satisfactorily identified. Significant properties recorded for this mineral are:

Colorless; one good cleavage; $\alpha = 1.685 \pm 0.002$; $\gamma = 1.695$; $\gamma - \alpha = 0.010$; $2V = 35 - 40°$ (+).

These data suggest zoisite but dispersion is absent and that mineral has somewhat higher refractive indices; furthermore zoisite is attracted by much weaker field strengths than used here.

In the —60 + 115 fraction of material from the mouth of Gazos Creek rare fragments were noted with the following properties:

Colorless, rounded fragments; $\alpha = 1.731 \pm 0.002$; $\gamma = 1.752$; $\gamma - \alpha = 0.021$; $2V = 65°$ (—); $r > v$, very strong. No chemical data are available.

PROVENANCE

Although detailed studies have not reached a state of completeness that would permit an adequate report concerning provenance, it may be stated that all of the minerals recognized in the beachsands with the exception of cassiterite, chrysoberyl, corundum, diamond, dufrenite, euxenite, scheelite, tantalite, thorite, vesuvianite, and xenotime have been found in assemblages of heavy mineral fractions prepared from Cretaceous and Tertiary sandstones, siltstones, volcanic ash beds, etc., in this area. Undoubtedly these must have provided much of the detritus that is now differentially sorted and concentrated on the present day beaches.

Study of heavy fractions prepared from soft brown sandstones of the Merced formation [1] (Lawson, 1914) proved instructive and pointed to a source for at least some of the deeply etched pyroxenes previously described, since both orthorhombic and monoclinic forms are very well represented in —60 + 115 and —115 size fractions of the large residues.[2]

The mineral frequencies, based on averaged counts of 300 grains in each of three samples of Merced sandstones, are set out in table 13. The dominance of green hornblende is noteworthy, particularly since this is characteristic of beach sands concentrated at the north end of Halfmoon Bay (see Princeton samples, table 1, earlier in the text).

In almost all respects the constituents in these assemblages (table 13) are comparable to those described earlier, but the following differences in mineralogy and association should be noted:

[1] These were collected at the north end of Moss Beach, approximately 2½ miles north of Princeton. The sandstones immediately overlie course dioritic and granodioritic conglomerates which in turn rest upon Montara intrusive rocks.
[2] These averaged 2.6 percent of the total samples employed.

Table 13. Mineral frequencies in heavy residues from brown sandstones of the Merced formation.

	—60 + 115	—115
Apatite	1	1
Augite	5	6
Biotite	1	-
Clinozoisite-epidote	4	4
Composites	6+	5
Garnet	1	
Glaucophane	1	1
Hornblende, green	7—	6+
Hornblende, brown	5	4
Hornblende, oxy-type	4	2
Hypersthene	4	6+
Kyanite	1	-
Opaque minerals (incl. chromite)	1	5
Rutile	1	-
Sphene	2	4
Staurolite	1	-
Zircon	1	1
Zoisite	1	-
Doubtful identification	-	1

(1) Habit of the constituents of the assemblages, irrespective of grain-size, is dominantly angular and accordingly this leads one to suggest that vectorial solution of pyroxene and amphibole fragments is actually taking place in these sediments, and is a normal process of the weathering of such material.

(2) Brown and green hornblendes are often mere relicts within wide peripheral zones of later formed colorless tremolite. This is most suggestive of a transformation of hornblendes of igneous and other origin into non-aluminous amphiboles, or at least amphiboles with a minimum of four-coordinated aluminum, that are stable at the low temperatures and pressures of sediments.

(3) Semi-nephrites were found among the composite fragments.

(4) Rare deep red-brown biotite has a wide optic axial angle ($2V = 48° \pm 2°$) and such pronounced dispersion that basal plates do not go into extinction between crossed nicols, but instead merely change from red to greenish-blue on rotation of the microscope stage.

(5) Staurolite and kyanite, both representative of a high grade of metamorphism are present.

Montara quartz diorite crops out over a wide portion of the distributive province at the northern end of the area treated here and heavy fractions prepared from 22 samples, though exceedingly small in volume, contained the following: hornblende, biotite, zoisite, clinozoisite-epidote, colorless zircon, sphene, opaque iron oxides, and very rare monazite; thorite was not found in any of these assemblages.

When distribution of augite was discussed earlier, attention was called to the dominance of augite in the —250 mesh fractions of sands found on beaches between the outlets of Butano, San Gregorio, and Pomponio Creeks, when ordinarily it is a relatively unimportant constituent of that size fraction. Accordingly a number of sediments cropping out near and within the drainage areas of those streams were studied. As a result so-called sandstones reportedly belonging to the Purisima formation and cropping out as prominent cliffs north of the mouth of San Gregorio Creek were found to consist almost entirely of finely comminuted rhyolite glass particles ($n = 1.497 - 1.503$; dominantly 1.500; see George, 1924, pp. 365, 368). Furthermore, the heavy mineral assemblages separated therefrom consisted largely of euhedral grains of augite and hornblende averaging less than 62 microns in diameter. Clearly then, these pumice silts, together with contributions from local pillow lavas, have provided much of the fine-grained ferromagnesian constituents found in nearby sands.

Fractionation of samples of granitic rocks from the Monterey - Pacific Grove area yielded monazite with physical and chemical properties closely resembling those of monazite separated from neighboring sands. Thus it is suggested that the detrital monazite must owe its origin to disaggregation of local granitic rocks, a conclusion strengthened by the knowledge that both garnet and biotite of the sands and the intrusives are strictly comparable. Thorite was not detected in residues prepared from any of the granitic rocks, nor in the local beach sands for that matter.

At a later date, study of the minor accessory constituents of the sedimentary rocks of the Coast Ranges is contemplated in order to arrive at a clearer understanding of their mineralogy and thus to determine so far as is possible what is their contribution to local beachsands. But at this time no specific suggestions are offered concerning origin of thorite, tantalite, chrysoberyl, scheelite, and other minor constituents recognized during this study.

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